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## DEVELOPMENT OF SAFE SEPARATION CRITERIA FOR THE MANUFACTURE OF BLU BOMBLETS

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**US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND**  
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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>The purpose of this program is to obtain the safe separation criteria for in-plant activities involving bulk explosives and explosive-filled ordnance related to the manufacturing and assembly of BLU bomblets. The tests were carried out to simulate, as closely as possible, actual processing activities. They demonstrated that maintenance of specific separation distances can minimize property damage and reduce the probability of propagation resulting from a detonation. |                       |   |

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## 20. ABSTRACT (Continued)

## Test results indicated:

1. 27.3 kg cyclotol in cardboard containers require a safe separation of 5.5 m. If the cyclotol is in 3 mm thick 6061-T6 or 7075-T6 aluminum boxes, the safe separation distance is in excess of 8.2 m. If the aluminum boxes are shielded with 9 mm of kevlar bonded to the containers, the safe separation is reduced to 7.3 m.
2. BLU-63 A/B hemispheres in pouring trays can be conveyed safely with the trays in intimate contact as long as the riser is limited to 20 kg of explosive. 2.0
3. Loose BLU-63 A/B hemispheres must be at least 13 mm apart. Complete bomblets must be separated 25 mm to be safe.

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## INTRODUCTION

This report describes a series of full scale test evaluations which was conducted in support of the U. S. Army Plant Modernization Program and Activities of the Milan Army Ammunition Plant (AAP). These activities involve the manufacture and loading of BLU bomblets. The tests were conducted under the guidance of the Energetic Systems Process Division, U. S. Army Research and Development Command, Dover, New Jersey. The evaluations were divided into five groups of tests each answering the same questions about safe separation distances between bulk explosives and explosive ordnance during different processing activities. The primary areas of concern are:

- The transport of 27.3 kg of explosive in cardboard shipping cartons via a steel roller conveyor.
- The movement of 27.3 kg of explosive in 6061-T6 and 7075-T6 aluminum containers along a pendant type conveyor.
- The processing of freshly poured BLU hemispheres in an 6061-T6 aluminum pouring tray moved by a belt conveyor.
- The movement of BLU hemispheres either loose or in a holding fixture along a belt conveyor.
- Assembled BLU bomblets, with fuze and booster pellets, conveyed on a belt conveyor.

The objectives of the test series were to determine whether a detonation at any stage of the processing operation would be limited to that point and propagation would be controlled by the separation distances.

The succeeding sections of this report detail the experimental test procedures, the results achieved, the conclusions drawn where applicable, and recommendations.

A short section of this report presents a very preliminary model of the safe separation distances. This model is based on the test data that were generated. No attempt was made to conduct experiments to provide data for the model since it was not the purpose of this program to model safe separation.

## DISCUSSION OF TEST PROCEDURES AND EVALUATION RESULTS

Safe separation tests were conducted with fixtures which simulated the in-plant configurations of the bulk explosives and the bomblets. In each series of tests, a donor charge was placed between a minimum of two acceptor charges at a distance predicated by the type of test performed and detonated. Results were taken from observations noted after each test and an analysis of motion pictures taken for each test series.

### Conveyance of Explosive (27.3 kg) on Steel Roller Conveyors

At the beginning of the manufacturing process, Cyclotol or Composition B, depending on the type of bomblet to be processed, is received in cardboard cartons, each containing 27.3 kg of explosive. This material is conveyed via a steel roller conveyor system to the next step in the processing cycle. The distance separating each box along the conveyor system is relative to the throughput and, at the same time, must meet the minimum requirements to produce a "no propagation" environment. A series of tests was conducted in open air (no confinement) to establish the minimum distance necessary. Each test conducted in this series was designed to simulate actual in-plant conditions. The donor charge was placed on a 1.5 m section of steel roller conveyor which in turn was situated atop of a Sonotube®\* pedestal at a height of 0.8 m, representing the height of the conveyor at the manufacturing facility. Each acceptor was placed on a like pedestal at a distance from the donor dictated by the results of previous tests. Distances were measured end to end. Figure 1 depicts a typical test arrangement. In each of the experiments conducted, the donor was top initiated by a J-2 or M-6 electric blasting cap in a booster of Composition C-4 weighing 0.10 kg.

The testing program began with a separation between the donor and acceptors of 2.3 m in open air (no confinement). At this distance, propagation by deflagration occurred which prompted an increase in the separation distance between donor and acceptors to 3.7 m. The charred area shown in Figure 2 is where each acceptor burned.

Three tests were performed at 3.7 m in open air where no propagations of any type took place. Based on these data, the donor and acceptors, spaced at 3.7 m, were placed in a tunnel constructed of steel angle iron 38 mm x 38 mm x 3.2 mm, 2.4 square x 14.6 long, sheathed with 0.8-mm thick corrugated fiberglass. Four tests were conducted which produced a detonation of an acceptor on the fourth test. These results seem to indicate that the tunnel, prior to destruction, provides a means by which fragments are focused by blast waves. However, an additional test at 3.7 m separation in open air resulted in propagation by detonation and deflagration.

As a result of the detonations at 3.7 m, the distance was increased by 0.9 m to 4.6 m separation. Nine tests were conducted which eventually resulted in propagation by detonation and deflagration. Twenty-two tests were then performed at 5.5 m separation. Two of 44 acceptors reacted by a burning of the explosive in the container as well as the explosive that was spilled.

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\* Registered trademark of Sonoco Products, Inc.

Table 1 outlines the experiments conducted without a tunnel while Table 2 shows the tests performed with the tunnel configuration.

During this phase of the testing program, it was noted that those acceptors which did not propagate were susceptible to damage ranging from slight to severe, depending on the distance maintained. Severe damage, similar to that shown in Figure 3, was not uncommon at distances up to 4.6 m. As can be seen, acceptor boxes were literally ripped open spilling their contents on the ground. Such damage was attributed to the rending effect large fragments had when striking the acceptors. Fragments were recovered from several acceptors and, in every case, were heavily encrusted with Cyclotol which had melted and resolidified. Figure 4 illustrates this phenomenon. In addition, close inspection and search of the residue from those acceptors which propagated by burning uncovered fragments ranging from very large to very small (Figure 5) which could have retained sufficient thermal energy to ignite the contents of the acceptor charges.

To ascertain that the secondary fragments generated by the steel roller conveyor were the sole contributing factor to propagation, a series of full scale tests was conducted without the conveyor system. In these tests, donor and acceptor charges were placed on Sonotube<sup>®</sup> pedestals at separation distances of 3.7 m, 5.5 m and 7.3 m. Table 3 catalogs the number of data points collected and the results. As noted, detonation propagation did not occur at any distance; however propagation by burning occurred at 3.7 m and 5.5 m. Close investigation of those acceptors which did not burn at 3.7 and 5.5 m revealed that the cardboard boxes were perforated by cardboard fragments evolving either from the donor box or the Sonotube<sup>®</sup> pedestal. It is conceivable, therefore, to assume such fragments traveling at velocities sufficient to penetrate the acceptor boxes could be burning or smoldering upon penetration thus providing the ignition source for the explosive.

These experiments, in conjunction with those tests with the steel roller conveyors (Tables 1 and 2) indicate that the introduction of any materials, such as a conveyor system, which produce secondary fragmentation, increases the probability of propagation by detonation. This observation, therefore, indicates that the use of steel roller conveyors in the plant operation requires separation distances between boxes to be at least 5.5 m.

#### Movement of 27.3 kg of Bulk Explosive Via Pendant Conveyors in Aluminum Boxes

Flaked Composition B or Cyclotol, depending on the bomblet to be produced, is moved from an unpacking facility to the melt kettle by means of aluminum containers on a pendant type conveyor system. Each aluminum container carries 27.3 kg of explosive.

In the beginning of the program the statement of work for this project indicated that phenolformaldehyde buckets would be used and these would be transported on steel roller conveyors. However, the user agency indicated at a later date that these containers would be changed to 6061-T6 aluminum containers. On this premise, a series of full scale experiments on steel roller conveyors was started with aluminum boxes constructed of 6061-T6 aluminum, 3 mm thick, with dimensions of 326 mm wide x 457 mm long by 226 mm high.

As with the cardboard boxes, the aluminum containers were placed on Sonotube<sup>®</sup> pedestals, the donor on a section of roller conveyor, and each acceptor separated from the donor by the distance prescribed for that specific test. These experiments were conducted in open air without the confinement of a tunnel. Propagation by detonation occurred at separation distances of 3.7 m, 4.6 m, and 7.3 m. Three experiments at 9.1 m produced no propagation. However, at this spacing numerous perforations of the acceptor boxes by various size fragments were noted. Table 4 lists all of the above tests and the results.

When it was made known that movement of the aluminum containers would be accomplished by a pendant conveyor, a series of tests was performed, suspending the 6061-T6 aluminum boxes pendant style, as illustrated in Figure 6.

Five tests were conducted with the pendant configuration and, like the tests on steel roller conveyors, propagation by detonation or burning occurred at distances up to and including 8.2 m (Table 5). No propagation transpired at 9.1 m, but each acceptor box was perforated on the side of the container facing the donor. Figure 7 illustrates the types and severity of fragment penetration on the acceptor boxes.

The results of this experiment again tentatively established a safe separation of 9.1 m, which did not meet the proposed spacing desired by the user agency, Milan AAF.

Theorizing that the 3-mm thick containers fragmented into relatively large fragments traveling at very high velocities, consideration was given to reducing the thickness of the aluminum containers to 1 mm in an effort to produce smaller fragments. Utilizing 6061-T6 containers, 1-mm thick, a test was conducted at 3.7 m separation producing one propagation by burning. The other acceptor broke apart at its welds, spilling its contents on the ground (Figure 8). On the basis of these results, a series of tests was carried out using aluminum boxes, 1-mm thick, constructed of a more brittle alloy, 7075-T6, in an effort to produce a fragment environment of very small fragments which might reduce the probability of perforation of an acceptor charge. Four experiments were performed at 3.7 m (Table 6) which produced three burn propagations, and recovery of that side of the acceptor boxes facing the donor indicated the size of the fragments was smaller, but the number of perforations was greater. Figure 9 depicts the typical size and number of penetrations observed.

One test was conducted at a distance of 5.5 m, with the donor and acceptor charges placed in a tunnel (2.4 m square x 14.6 m long) manufactured of steel angle iron (38 mm x 38 mm x 3.2 mm) sheathed with 0.8 mm thick fiberglass (Figure 10). This test produced the burn of one acceptor (Table 7). Figure 11 illustrates the residue from the acceptor that burned, while Figure 12 depicts the residue from the acceptor that did not propagate.



The results of the tests performed indicated the probability of propagation by detonation was significantly reduced, but did not realize a no propagation environment. In addition, the flexibility of the 1-mm thick containers caused concern relative to their serviceability in everyday use at the plant.

In discussions with the ARRADCOM officials, the idea of placing shields between the donor and acceptors, which might defeat or deflect fragments and still allow the use of the more rigid 3-mm thick container, was entertained. Acting on this suggestion, one test was planned and carried out utilizing a 6061-T6, 3-mm thick aluminum box, filled with 27.3 kg of Cyclotol. Three shields of mild steel, measuring 1.6 mm thick, 2.3 mm thick, and 3.2 mm thick, were suspended 1.8 m from the charge, and one shield 3.2 mm thick was placed 2.7 m from the charge (Figure 13). The explosive was detonated and the results proved this type shielding to be ineffective. The shields failed to defeat the fragments, but enhanced the hazard in that upon penetration of aluminum fragments, steel fragments were formed. In addition, the steel shielding was projected by detonation of the charge to distances in excess of 150 m. Figure 14 depicts the perforations of the steel shields and graphically illustrates their ineffectiveness.

At the conclusion of this experiment, an idea was presented to attempt to shield each aluminum container with some type of armor which would produce innocuous fragments if attached to a donor charge but still have the capability to defeat fragmentation from the donor if attached to an acceptor. The armor most accessible to Southwest Research Institute was 9.5-mm thick Kevlar®\* material. In an effort to verify the effectiveness of this concept, one experiment was hastily performed whereby the 3-mm thick 7075-T6 aluminum containers were shielded with Kevlar attached to the outside of the donor and each acceptor. One side of the donor and one acceptor were shielded by Kevlar 19 mm thick, while the other side of the donor and one acceptor were shielded by a single thickness, 9.5 mm. The acceptor with the 19 mm thickness was placed at a distance of 3.7 m from the donor and the single thickness, 9.5 mm shielded acceptor was placed 4.6 m from the donor. This experiment was conducted in a tunnel constructed of 38 mm x 32 mm x 3.2 mm steel angle iron, measuring 2.4 m square and 14.6 m long and sheathed with 0.8-mm thick fiberglass. Upon initiation of the donor, acceptor No. 1, situated at 3.7 m from the donor and sheathed with 19 mm of Kevlar detonated, while the other acceptor, shielded with 9.5 mm of Kevlar, burned (Table 8). This experiment indicated that the Kevlar shielding did have an effect on reducing the probability of propagation by detonation.

Milan specified that the minimum thickness acceptable for aluminum boxes was 2.3 mm, and that containers would be constructed with a pyramid-type bottom rather than a flat bottom, as shown in Figure 15. Using 2.3 mm 7075-T6 aluminum containers, tests were carried out in a fiberglass-sheathed tunnel of the same dimensions as the pre-

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\* Registered trademark of E. I. DuPont de Nemours & Company, Inc.

vious test. The tunnel simulates the ramps through which the aluminum containers pass at the AAP. Each container was suspended pendant style and the donor and each acceptor was shielded with 9.5 mm-thick Kevlar armor (Figure 16). In addition, a 127-mm thick wallboard collection medium was placed immediately below each acceptor to collect fragments to ascertain size and penetrating ability. Beginning at 5.5 m separation, one test was performed which resulted in the burn of each acceptor. This occurrence prompted an increase in the distance between donor and acceptors to 7.3 m (Table 9). At this spacing, propagation by detonation did not occur and only one acceptor burned. Figure 17 illustrates the overall condition of the acceptors after each test. As noted, the acceptors came apart where the containers were welded together thereby spilling their contents on the ground.

Close inspection of the side of the acceptor boxes which faced the donor revealed that the Kevlar armor did retard the penetrating effects of aluminum fragments projected by the detonation of the donor charge. The severest damage to the aluminum wall of the container is graphically illustrated in Figure 18, in that the facing is dented and cracked, but not perforated. Figure 19 depicts the most common damage inflicted on the acceptors.

Fragments recovered from the wallboard ranged in size from 0.15 g to 1 g in weight and in various geometric shapes. The maximum penetration noted was 76 mm. Table 10 lists the typical fragment distribution and penetrations noted during the conduct of these experiments.

#### BLU Hemispheres in 6061-T6 Aluminum Pouring Trays

The next process in the manufacturing of BLU bomblets requires the filling of male and female hemispheres with cast Composition B or Cyclotol. To accomplish this, 16 hemispheres are placed under a tray and passed under a pouring apparatus. Each pouring tray is constructed of an aluminum alloy, 6061-T6, fitted with steel inserts to facilitate the void needed for the fuze cavity. Each tray with an 3 mm wall thickness measures 330 mm long by 330 mm wide by 40 mm high. These trays are conveyed on a belt conveyor butted one against the other, side-by-side and end-to-end.

Using a 6061-T6 aluminum tray without the steel inserts but still maintaining the overall dimensions, a testing program was begun. The experiments evaluated the safe separation distance required between pouring trays having 16 BLU hemispheres, each filled with Composition B, and a riser containing 3.4 kg of flaked Composition B. These were positioned on a simulated belt conveyor, and separated by a distance based on the results of previous testing. Initiation of the donor was accomplished by a booster of Composition C-4 (0.050 kg) and a M-6 electric blasting cap. Figure 20 is a typical test setup for this phase of the project.

As the testing progressed, it was observed that at distances of 1 m and 0.5 m separation (Table 11) the risers of the acceptors burned and this action continued through the base of the tray to the BLU hemispheres. In addition, because the 3.4 kg of Composition B heaped well above the riser wall at distances of a few inches or less, it was assumed that propagation by detonation

became a high risk factor. For this reason and to facilitate the current production practice of abutment of the pouring trays, the riser content was reduced from 3.4 kg to 2.0 kg of flaked Composition B. This reduction in the riser brought the explosive well below the riser wall which allowed for testing with the pouring trays against each other. Each test was conducted in the same manner as those with 3.4 kg riser (Figure 27) and no propagations were observed during that testing cycle (Table 12 ). Figure 22 exemplifies the typical results achieved with a 2.0 kg riser with no separation between trays. Note that some hemispheres are relatively unscathed while others have the sheet metal shroud (airfoil) missing, and others have had the explosive filler jarred out of the serrated shell. In each test, the damage to the acceptor pouring trays consisted of the loss of the riser sides and the side next to the donor charge was curled downward.

#### BLU 63 A/B Hemispheres Loose on a Belt Conveyor

After the hemispheres are poured, they are broken loose from the pouring tray, dumped on a feed table, and allowed to pass in a random fashion on a conveyor belt to the next station of the processing operation. At present no consideration is given to separation distances in this activity and hemispheres may be in contact with each other or separated by as much as 305 mm.

The task required by this phase of the program was to determine, via full scale testing, a minimum safe separation that would preclude propagation from hemisphere-to-hemisphere by detonation. The experiments began at a 152-mm spacing between the donor and each acceptor hemisphere, and then spacing was progressively reduced until propagation by detonation occurred. This event took place when the hemispheres were in contact.

Figures 23 through 25 depict a typical test arrangement and the ensuing results. Figure 22 involved a test where the separation distance was 25.4 mm between the donor and each acceptor. The donor hemisphere was initiated by a M-6 or J-2 electric blasting cap with an 0.011 kg booster of Composition C-4. The white canvas material is the simulation of a belt conveyor.

The severity of the damage sustained by the acceptors from the initiation of the donor is relative to separation distance, and Figure 24 shows the damage incurred by an acceptor at 51 mm. Figure 25 illustrates the increase in damage to acceptor hemispheres at less separation. In Figure 24 the sheet metal shroud is intact although it was perforated by a fragment from the donor which very nearly penetrated the steel serrated casing. At 25.4 mm separation (Figure 25) the damage is more severe in that the sheet metal shroud has been partially torn away and the serrated steel casing has been deformed as a result of fragment hits. In both cases, the explosive filler was dislodged and scattered over the ground at the test site.

Table 13 summarizes all of the safe separation tests which were conducted with the BLU hemispheres and includes 25 confirmatory tests which were carried out at 13 mm separation with no propagations.



## BLU Hemispheres Held in Steel Holding Fixtures

To feed the BLU hemispheres into the facing and drilling operation each hemisphere is fitted into a steel fixture. At first glance it would appear the steel fixture could contribute fragments from a detonation of the hemisphere enhancing the possibility of propagation to a neighboring hemisphere in a fixture.

Beginning at 152 mm separation between fixtures, a series of experiments was conducted to determine the minimum distance required between fixtures having hemispheres installed. Distances were reduced until a point was reached where there was no separation between fixtures. Because of the larger diameter of the holding fixture, the distance between hemispheres is approximately 19 mm when fixtures are touching. This distance is in excess of the 13 mm separation established for hemispheres in a loose configuration.

Figure 26 illustrates a typical test setup and initiation is accomplished in the same manner as loose hemispheres described earlier in this report. Damage sustained by the hemispheres ranged from none to very minor, depending upon the separation distance for that particular test. In almost all cases, however, the fixture containing the donor was shattered and the acceptor fixtures remained intact while experiencing fragment hits which left impact marks (Figure 27).

Table 14 outlines all of the tests which were fired in this phase of the program. The table includes 25 confirmatory tests performed with no separation between fixtures. There were no propagations.

## Safe Separation of Assembled BLU Bomblets on a Belt Conveyor

After the drilling and facing of the hemispheres, the fuze assembly is placed in the cavity provided, the halves mated and crimped together. The bomblets, now complete, are placed on a belt conveyor. The placement of the bomblets on the conveyor is random and unconstrained with regard to maintenance of a safe separation distance. This phase of the program, therefore, was to experimentally determine a minimum distance between bomblets which would preclude the propagation from one unit to the next along the conveyor system.

Testing began at a separation of 152 mm, at which distance, the acceptor bomblets remained intact, although each experienced severe fragment hits. From this point, the distance between the donor bomblet and each acceptor bomblet was progressively reduced until propagation occurred. Each test was conducted on a simulated belt conveyor, and the donor was initiated by utilizing an electric blasting cap with a 0.036 kg booster of Composition C-4 (Figure 28). Damage to the acceptor bomblets increased in severity as the distances became less, until at 13.0 mm propagation occurred. Beginning at 76 mm, the action of the blast and fragments on each acceptor caused the bomblets to separate where the two hemispheres were mated, and the fuzes were dislodged from their cavities. However, they were normally found in the immediate vicinity of the test location. Figure 29 illustrates the degree of damage sustained by the acceptor bomblets when the distance



between donor and acceptors was 25.4 mm. Note that the fuzes are still intact, explosive has been dislodged from a hemisphere and the deformation caused to one bomblet by fragmentation of the donor. In almost all cases, the sheet metal shrouds were ripped from the serrated shells by blast and fragmentation. Dislodged explosive fillers were generally found on the ground in the immediate vicinity of the test site (Figure 30).

At 13 mm separation, the residue recovered indicated that a more violent effect was experienced by the acceptors than observed when the separation distance was 25.4 mm. In each of the tests conducted at 13 mm, instead of the recovery of four hemispheres and two fuzes, the residue included some hemispheres, fragmented portions of hemispheres, and pieces of the fuze assembly. In some cases, one or more of the hemispheres recovered were blackened indicating the explosive filler burned. Figure 31 illustrates a complete hemisphere, a fragment of another and the recovered fuze components. Based on this data it was concluded that separation distances of 13 mm, or less, are not safe. Tests conducted at separation distances of 25.4 mm and 51 mm indicated no detonation propagation and one burning propagation at 51 mm. Table 15 summarizes all tests performed.

## PROPAGATION PREDICTION

Safe separation experiments are generally conducted in two series: 1) exploratory tests; and 2) confirmatory tests. The exploratory tests begin at a data point and then, based on success or failure, gravitate toward a "safe separation" distance. Confirmatory tests are then conducted at this distance to assure that no propagation occurs. There exists no official protocol for the experimentation procedure and the only basis for the starting point is the background and experience of the experimentalist.

A viewpoint that has had a deleterious effect on the analysis of safe separation is that the result of any experiment is binomially distributed; either the experiment produced a success or a failure. Some techniques, such as the Bruceton or Modified Bruceton method yield additional statistical data. However, statistics are routinely employed merely to verify that the safe separation distance identified is indeed safe. It would be nice if: there is a basis other than success or failure to predict the probable success of future tests after the first data point is determined; there is a basis for comparing trends for similar configurations; and there exists a model to allow a more accurate prediction of the starting point of the experimentation and, hopefully, the final separation distance. Some of these goals are discussed below.

The experimental data developed on this program were not structured to provide a basis for modeling safe separation. That would require either the accumulation and analysis of significantly more data or the structuring of a particular program toward this end. However, the separation distance data generated in this program have been organized to provide an insight to the predictability of safe separation.

The first step in organizing the experimental data was to recognize that the "go - no go" criterion can be expanded into a gross probability of occurrence relationship merely by dividing the number of successes (or failures) by the number of data points at each test condition. These data can then be plotted against distance. In this case, a scaled distance is employed in which the physical distance is divided by the cube root of the weight of the explosive to yield the "scaled distance."

The next step was to recognize that propagation for close distances can be in the form of detonation propagation and as the distance is increased the effect becomes one of fire propagation. A third propagation criterion is often imposed which relates to no propagation; i.e., no detonation or fire propagation is acceptable. The data then must be arranged to reflect all three criteria.

In general, it would be expected that any model which predicts detonation propagation will differ from a model which predicts burn propagation. Also, the no burn or detonation propagation (no propagation) model can be expected to be peculiar. To this end, then, the experimental data were cast into the three alternative criteria and trends were postulated. Figures 32, 33, and 34 show the test data for no detonation, no burn, and no propagation, respectively. The number in parentheses next to each graph

data point represents the number of test data points at that particular condition. Symbols are defined in the body of the figures.

It was important to determine if the data followed trends which could be defined. Since this is a very preliminary analysis, no attempt was made to establish an all inclusive model. Indeed, the pertinent parameters were not structured in a similitude model arrangement because many were common to this particular set of experiments and the data base is severely limited. It was interesting to observe, however, that the probability function of the event with respect to the scaled distance could be cast into a general form of:

$$P = \left[ \sin \left[ \frac{[X - X_0]}{[X_{100} - X_0]} \left[ \frac{\pi}{2} \right] \right] \right]^{.21} \quad (1)$$

where  $P$  = Probability of no propagations, burns, or detonations as applicable

$X$  = scaled distance,  $m/kg^{1/3}$

$$\left( X = \frac{S}{C^{1/3}} \quad \text{where: } S = \text{separation distance, m} \right. \\ \left. C = \text{charge weight, kg} \right)$$

$X_0$  = Characteristic scaled distance for 100% propagation, burn, or detonation,  $m/kg^{1/3}$

$X_{100}$  = Characteristic scaled distance for 0% propagation, burn, or detonation,  $m/kg^{1/3}$

From Figures 32, 33 and 34 it can be seen that the general relationship of equation (1) can be fitted to the experimental data. The problem, clearly, is to characterize  $X_0$  and  $X_{100}$  in terms of the parameters of the explosive devices and adjacent equipment. This was accomplished to a very limited extent for generically similar devices. Table 16 shows the  $X_0$  and  $X_{100}$  values for each of the conditions evaluated. The symbols used in the table relate to the test conditions given in Figures 32, 33, and 34.

From these data it was found that  $X_0$  and  $X_{100}$  could be approximated by the relations:

$$X_0 = 1.715 \left( \frac{C}{M} \right)^{0.4265} - 1.370 \quad (2)$$

$$X_{100} = 4.259 - 3.251 \left( \frac{C}{M} \right)^{-0.5205} \quad (3)$$

where:  $M$  = weight of metal, kg

The relationship was reasonable for  $0.61 \leq \frac{C}{M} \leq 6.37$ . This limited relationship does not provide a reasonable fit for the tests in which cardboard containers were used or for the BLU 63A/B hemispheres. In the instance of the cardboard boxes it is felt that the cardboard probably does not provide a significant confinement and the trends should be closer to those of bare charges. Also, it is probable that the safe separation distance may relate more closely to the blast and fireball effect than to fragment impact effects. Conversely the other configurations appear to relate more closely to fragment impact effects. There also appears to be a configuration effect which cannot be defined without more experimentation.

An examination of Figures 32 through 34 indicates:

- 1) The general relationship  $[P = (\sin AX)^n]$  provides a reasonable approximation of the probability of no event versus scaled distance. An "S" shaped relationship was expected since the lower threshold was expected to provide a gradual onset and the upper region a transition zone. Once a sine relationship was postulated it was easy to fit a set of similar curves through most of the data points. The primary problem relates to the lack of sufficient data points at some of the test conditions to allow a firm definition of the relationship.

The transition region near the top of the curves needs to be explored more precisely. Unfortunately, in this particular region it appears that a significant number of data points are needed at each test condition to provide a firm basis for characterizing the curve. As an example, consider the case of the BLU 63A/B bomblets in a no-burn propagation environment (Figure 33). At a scaled distance of 0.048, 46 out of 46 tests indicated no burn propagation. Yet, at a scaled distance of 0.097 one burn out of 50 tests resulted. The point of 100% probability of no event, then, is not easily established by experimentation alone.

The sharpness of the curve indicates that a significant increase in safety can be gained by a relatively small increase in the scaled distance. If a little planning is used to set up safe separation criteria for a particular process, much can be gained in terms of real safety and cost by the use of a probabilistic relationship such as that described in equation (1). In many applications the safety objective is to prevent propagation down a line. If a safe separation model is developed along the generic lines of equation (1), it should be possible to provide a reasonable estimate of the probability of propagation through the use of the model. This, in turn, will: 1) Allow process configurations to be designed in which there is a low probability of producing

a chain reaction merely by the application of analytical techniques; and 2) reduce the number of tests required to confirm safe separation.

- 2) At the higher C/M ratios (~15) the limited relationship for  $X_0$  and  $X_{100}$  does not describe the "correct" values adequately. The model must be amplified to allow the expansion of the C/M range. The confinement material characteristics must be incorporated into the model in a manner more rigorous than merely including the mass. Strength and configuration effects will probably need to be added.
- 3) The curves for the Cyclotol in cardboard boxes, with or without a tunnel (Symbols ■ and Δ) are about equal. This implies that in an environment that is primarily blast and/or fire the relatively light tunnel has little influence on the safe separation distance. Apparently a significant amount of energy is not reflected back from the walls and roof of the tunnel and directed toward the acceptor. If the tunnel mass is increased - by making the tunnel stronger or by snow and ice accumulation - some energy focusing effect could be expected which, in turn, would separate the two curves.
- 4) As the Cyclotol confinement is diminished to a wall thickness of about 1 mm 7075-T6 or 6061-T6 aluminum, the probability of burn and no propagation approaches that of the Cyclotol in cardboard boxes (see symbols ∇ and ◆ in Figures 33 and 34).
- 5) There is no significant difference in safe separation for thick (3 mm) aluminum boxes with steel roller conveyors or pendant conveyors (Symbols ▲ and ◇). The two conveyor configurations differ significantly (more conveyor fragments could be expected from the roller conveyor). However, it is apparent that the primary mode of propagation is through the fragments produced from the boxes. The conveyor fragments result in a lower probability threat.

One trend that could not be explored in the program is that of configuration. The boxes were square or rectangular in their plan view. When they were separated they were lined up plane-to-plane (□ □). Since fragments tend to leave the box normal to the surface, the donor fragments tend to be directed, for the most part, in a plane aimed at the acceptor. If the boxes were lined up so as to be rotated 45° (◇ ◇), a lower fragment density could be expected at the acceptor box location.

- 6) In general - the higher the C/M, the higher the requisite standoff. This trend is not universal since the cardboard box configuration has a higher C/M than does the aluminum box configuration and yet it has a shorter standoff. Clearly, there is a material effect as well.



## CONCLUSIONS

The full-scale tests conducted relative to in-plant operations within the BLU bomblet manufacturing complex were very successful. The test program demonstrated that most operations currently in use are within safe limits. Some processing activities require only minor changes, while others need more stringent changes. Every effort was made to facilitate the desires specified by the user agency relative to safety and production efficiencies. Based on the test program conducted, the following conclusions are drawn:

1. The most serious problems arose in the conveyance of bulk Cyclotol, in 27.3 kg quantities, in both cardboard containers on steel roller conveyors and in aluminum containers on pendant type conveyors. In the cardboard cartons on steel roller conveyors, propagation by detonation occurred at 3.7 m and 4.6 m, while the aluminum containers propagated by detonation at distances up to and including 8.2 m.

2. In the case of the Cyclotol in cardboard boxes, the only practical solution was an increased separation distance. Extensive testing was performed at 5.5 m, with only one propagation by burning. However, in some of the tests, the acceptor boxes were heavily damaged by fragmentation from the roller conveyor. On the basis of these observations, it may be assumed that propagation by detonation is conceivable if an acceptor charge is subjected to being hit by a fragment large enough and traveling fast enough. Though the experiments performed in this program did not produce a detonation of an acceptor at 5.5 m, it is concluded that such a propagation is statistically possible and that the safe separation distance between boxes of Cyclotol containing 27.3 kg of explosive be at some distance in excess of 5.5 m.

3. With propagation by detonation occurring at 8.2 m separation between aluminum boxes suspended pendant style, several options were presented to allow lesser distances. The first option was to reduce the thickness of the containers to produce smaller, more innocuous fragments. A second option was the placement of some type of shielding between boxes which might defeat or deflect the fragmentation generated by a donor charge upon detonation, while the third option entailed the use of a Kevlar shield attached directly to the donor and acceptor charges in an effort to defeat the capability of fragments to penetrate adjacent containers in the conveyor system. Each option was tested with the following observations:

- The thinner wall containers reduced the distance between donor and acceptor charges significantly. However, because these containers are extremely flexible they were not conducive to the serviceability criteria needed for daily in-plant use and were rejected for use by the user.
- The introduction of shields, suspended between containers, proved to be very ineffective. Such shielding, rather than defeating fragmentation, enhanced the fragmentation environment by adding to such fragmentation.

- Using a more rigid container, such as specified by the user agency, with a 9 mm thick Kevlar shield attached, distances were reduced between donor and acceptor charges from 9 m to 7.3 m.

4. For BLU hemispheres and BLU bomblets in various processing configurations, the following observations were noted:

- BLU Hemispheres Loose on a Belt Conveyor

As discussed in the previous section, the testing of BLU hemispheres on a belt conveyor revealed that propagation by detonation did occur when hemispheres were placed in contact with each other. As noted in Table 13, out of eight data points, three hemispheres propagated. It was concluded that testing at intermediate distances between 0.0 mm and 13 mm separation could conceivably produce the same results. Confirmatory tests were therefore conducted at 13 mm separation, and this distance proved satisfactory in providing the separation necessary to preclude propagation from one hemisphere to the next during the conveyance of these articles to the next processing station.

- BLU Hemispheres in Steel Holding Fixtures

No propagation between hemispheres takes place when the fixtures are abutted together. In this configuration, the hemispheres, being smaller in diameter than the fixture, are spaced apart by the 13 mm found to be effective in the loose hemisphere phase of the program.

- BLU Hemispheres in Pouring Trays

BLU hemispheres when positioned in the pouring trays are, due to the design of the tray, nominally separated by at least 13 mm. This condition, as detailed in the tests involving loose hemispheres, reduces the probability of propagation by detonation stemming from hemisphere to hemisphere. The problem of propagation lies in the quantity of explosive in the riser of the pouring tray rising above the side wall of the pouring tray. In actual plant conditions the 3.4 kg of molten Comp B would obviously not extend over the side wall of the pouring tray.

- BLU Bomblets Complete with Fuze Assembly

The BLU bomblet assembled with the fuze will propagate when it is in direct contact with the donor bomblet. At 13 mm separation, the test program indicated the action of the donor on the acceptors is very severe. Acceptors at this distance tend to fragment, while the fuzes generally break up from some external force. This is considered marginal in that the condition of the acceptors at 13 mm separation versus 25 mm separation, shows that the threshold of propagation by detonation is imminent. For this reason, 25 mm is considered the safe separation.

Table 17 outlines the results achieved as dictated by the testing program.



## RECOMMENDATIONS

1. It is recommended that consideration be given to the evaluation of a different means of conveying 27.3 kg of Cyclotol in cardboard boxes. The fragmentation of the steel roller conveyor, directly below and adjacent to a donor charge, creates an environment which can produce a propagation by detonation at distances in excess of 5.5 m.
2. Aluminum containers used to convey bulk Cyclotol from one processing activity to the next should be shielded by Kevlar shields having a minimum thickness of 9 mm. In addition, it is recommended that such shielding be bonded to the aluminum containers.
3. Conveyor belts utilized in the movement of loose hemispheres and complete bomblets should be a type that ensures the separation distances found to be adequate by this testing program are maintained.
4. It is recommended that these activities involving the movement of bulk explosives be equipped with an approved hardened water deluge system to extinguish secondary fires which might result from a detonation.

Table No. 1

Test Configuration: Safe separation of 27.3 kg of Cyclotol in cardboard shipping cartons on steel roller conveyor - without tunnel

| Separation Distance (m) | Number of Tests | Number of Data Points | Number of Detonations | Number of Burns | Number of no Propagations | Percent No Detonations | Percent No Burns | Percent No Propagations |
|-------------------------|-----------------|-----------------------|-----------------------|-----------------|---------------------------|------------------------|------------------|-------------------------|
| 2.3                     | 1               | 2                     | 0                     | 2               | 0                         | 100                    | 0                | 0                       |
| 3.7                     | 4               | 8                     | 1                     | 1               | 6                         | 87                     | 87               | 75                      |
| 4.6                     | 9               | 18                    | 1                     | 1               | 16                        | 94                     | 94               | 89                      |
| 5.5                     | 22              | 44                    | 0                     | 2               | 42                        | 100                    | 95               | 95                      |

Donor initiated with J-2 or M-6 electric blasting cap with 100 gram Composition C-4 booster

Table No. 2

Test Configuration: Safe Separation of 27.3 kg of Cyclotol in cardboard shipping cartons on steel roller conveyor - with tunnel

| Separation Distance (m) | Number of Tests | Number of Data Points | Number of Detonations | Number of Burns | Number of no Propagations | Percent No Detonations | Percent No Burns | Percent No Propagations |
|-------------------------|-----------------|-----------------------|-----------------------|-----------------|---------------------------|------------------------|------------------|-------------------------|
| 2.7                     | 1               | 2                     | 0                     | 1               | 1                         | 100                    | 50               | 50                      |
| 3.7                     | 4               | 8                     | 1                     | 0               | 7                         | 87                     | 100              | 87                      |

Table No. 3

Test Configuration: Safe separation 27.3 kg of Cyclotol in cardboard shipping cartons - no conveyance system - without tunnel

| Separation Distance (m) | Number of Tests | Number of Data Points | Number of Detonations | Number of Burns | Number of no Propagations | Percent No Detonations | Percent No Burns | Percent No Propagations |
|-------------------------|-----------------|-----------------------|-----------------------|-----------------|---------------------------|------------------------|------------------|-------------------------|
| 3.7                     | 2               | 8                     | 0                     | 4               | 4                         | 100                    | 50               | 50                      |
| 5.5                     | 4               | 10                    | 0                     | 1               | 9                         | 100                    | 90               | 90                      |
| 7.3                     | 6               | 24                    | 0                     | 0               | 24                        | 100                    | 100              | 100                     |

Donor initiated with a M-6 electric blasting cap with 100 gram Composition C-4 booster

Table No. 4

Test Configuration: Safe separation of 27.3 kg of Cyclotol in 6061-T6 aluminum boxes on steel roller conveyors - without tunnel

| Separation Distance (m) | Number of Tests | Number of Data Points | Number of Detonations | Number of Burns | Number of no Propagations | Percent No Detonations | Percent No Burns | Percent No Propagations |
|-------------------------|-----------------|-----------------------|-----------------------|-----------------|---------------------------|------------------------|------------------|-------------------------|
| 3.7                     | 1               | 2                     | 2                     | 0               | 0                         | 0                      | -                | 0                       |
| 4.6                     | 1               | 2                     | 2                     | 0               | 0                         | 0                      | -                | 0                       |
| 5.5                     | 1               | 1                     | 0                     | 1               | 0                         | 100                    | 0                | 0                       |
| 7.3                     | 1               | 2                     | 1                     | 0               | 1                         | 50                     | 100              | 50                      |
| 9.1                     | 3               | 6                     | 0                     | 0               | 6                         | 100                    | 100              | 100                     |

Donor initiated by a M-6 or J-2 electric blasting cap with 100 gram Composition C-4 booster

Table No. 5

Test Configuration: Safe Separation - 27.3 kg of Cyclotol in 6061-T6 aluminum boxes suspended pendant style - without tunnel

Aluminum Boxes - 356 mm wide x 457 mm long x 229 mm high x 3 mm thick (type 6061-T6)

| Separation Distance (m) | Number of Tests | Number of Data Points | Number of Detonations | Number of Burns | Number of no Propagations | Percent No Detonations | Percent No Burns | Percent No Propagations |
|-------------------------|-----------------|-----------------------|-----------------------|-----------------|---------------------------|------------------------|------------------|-------------------------|
| 3.7                     | 1               | 2                     | 2                     | 0               | 0                         | 0                      | -                | 0                       |
| 7.3                     | 1               | 2                     | 1                     | 1               | 0                         | 50                     | 50               | 0                       |
| 8.2                     | 1               | 2                     | 1                     | 0               | 1                         | 50                     | 100              | 50                      |
| 9.1                     | 2               | 4                     | 0                     | 0               | 4                         | 100                    | 100              | 100                     |

Donor initiated with a J-2 or M-6 electric blasting cap with 100 gram composition C-4 booster

Table No. 6

Test Configuration: Safe separation - 27.3 kg of Cyclotol in aluminum boxes  
suspended pendant style - without tunnel

Aluminum boxes - 356 mm wide x 457 mm long x 229 mm high x 1 mm thick

| Separation<br>Distance<br>(m) | Number<br>of<br>Tests | Number<br>of<br>Data<br>Points | Number<br>of<br>Detonations | Number<br>of<br>Burns | Number<br>of<br>no<br>Propagations | Percent<br>No<br>Detonations | Percent<br>No<br>Burns | Percent<br>No<br>Propagations |
|-------------------------------|-----------------------|--------------------------------|-----------------------------|-----------------------|------------------------------------|------------------------------|------------------------|-------------------------------|
| 3.7 <sup>1</sup>              | 1                     | 2                              | 0                           | 1                     | 1                                  | 100                          | 50                     | 50                            |
| 3.7 <sup>2</sup>              | 4                     | 8                              | 0                           | 3                     | 5                                  | 100                          | 62                     | 62                            |

Donor initiated by a J-2 or M-6 electric blasting cap with 100 gram Composition C-4 booster

1 - Aluminum Material 6061-T6

2 - Aluminum Material 7075-T6

Table No. 7

Test Configuration: Safe separation - 27.3 kg of Cyclotol in 7075-T6 aluminum boxes suspended pendant style - with tunnel

Aluminum boxes - 356 mm wide x 457 mm long x 229 mm high x 1 mm thick (type 7075-T6)

| Separation Distance (m) | Number of Tests | Number of Data Points | Number of Detonations | Number of Burns | Number of no Propagations | Percent No Detonations | Percent No Burns | Percent No Propagations |
|-------------------------|-----------------|-----------------------|-----------------------|-----------------|---------------------------|------------------------|------------------|-------------------------|
| 5.5                     | 1               | 2                     | 0                     | 1               | 1                         | 100                    | 50               | 50                      |

Donor initiated by M-6 electric blasting cap with 100 gram Composition C-4 booster



Table 8

Test Configuration: Safe separation - 27.3 kg of Cyclotol in 7075-T6 aluminum boxes with Kevlar shielding suspended pendant style - with tunnel

Aluminum boxes - 356 mm wide x 457 mm long x 229 mm high x 3 mm thick

| Separation Distance (m) | Number of Tests | Number of Data Points | Number of Detonations | Number of Burns | Number of no Propagations | Percent No Detonations | Percent No Burns | Percent No Propagations |
|-------------------------|-----------------|-----------------------|-----------------------|-----------------|---------------------------|------------------------|------------------|-------------------------|
| 3.7 <sup>1</sup>        | 1               | 1                     | 1                     | -               | 0                         | 0                      | -                | 0                       |
| 4.6 <sup>2</sup>        | 1               | 1                     | -                     | 1               | 0                         | -                      | 0                | 0                       |

Donor initiated by a M-6 electric blasting cap with 100 gram Composition C-4 booster

1 - Aluminum box shielded by Kevlar 19 mm thick

2 - Aluminum box shielded by Kevlar 9.5 mm thick

Table 9

Test Configuration: Safe separation - 27.3 kg of Cyclotol in 7075-T6 aluminum boxes with Kevlar Shielding (9.5 mm thick) suspended pendant style - with tunnel

Aluminum boxes - 406 mm square x 203 mm high (vertical sides)  
x 2.3 mm thick with pyramided bottom (type 7075-T6)

| Separation Distance (m) | Number of Tests | Number of Data Points | Number of Detonations | Number of Burns | Number of no Propagations | Percent No Detonations | Percent No Burns | Percent No Propagations |
|-------------------------|-----------------|-----------------------|-----------------------|-----------------|---------------------------|------------------------|------------------|-------------------------|
| 5.5                     | 1               | 2                     | -                     | 2               | 0                         | 100                    | 0                | 0                       |
| 7.3                     | 13              | 26                    | -                     | 1               | 25                        | 100                    | 96               | 96                      |

Donor initiated by M-6 electric blasting cap with 100 gram Composition C-4 booster

Table No. 10

Typical fragment distribution and weights

| Fragment Penetration (mm) | Fragment Weight (grams)              |
|---------------------------|--------------------------------------|
| 13 mm                     | 0.50<br>0.55<br>0.80<br>0.15<br>0.20 |
| 25 mm                     | 0.15<br>0.20<br>0.45<br>0.50         |
| 51 mm                     | 0.35<br>0.40<br>0.55                 |
| 64 mm                     | 0.60                                 |
| 76 mm                     | 0.40<br>0.85                         |

NOTE: The collection medium consisted of 10 pieces of Wallboard 13 mm thick bundled together to a total thickness of 127 mm.

Table No. 11

Test Configuration: Safe separation - 16 BLU hemispheres in 6061-T6 pouring trays on simulated belt conveyor with 3.4 kg riser of flaked Composition B

Pouring Tray - 385 mm square x 40 mm high x 8 mm thick

| Separation Distance (m) | Number of Tests | Number of Data Points | Number of Detonations | Number of Burns | Number of Propagations | Percent No Detonations | Percent No Burns | Percent No Propagations |
|-------------------------|-----------------|-----------------------|-----------------------|-----------------|------------------------|------------------------|------------------|-------------------------|
| 0.5                     | 2               | 4                     | 0                     | 2               | 2                      | 100                    | 50               | 50                      |
| 1.0                     | 1               | 2                     | 0                     | 1               | 1                      | 100                    | 50               | 50                      |
| 1.5                     | 2               | 4                     | 0                     | 0               | 4                      | 100                    | 100              | 100                     |
| 2.0                     | 1               | 2                     | 0                     | 0               | 2                      | 100                    | 100              | 100                     |
| 3.0                     | 1               | 2                     | 0                     | 0               | 2                      | 100                    | 100              | 100                     |

Donor initiated with J-2 or M-6 electric blasting cap with 4.050 kg Composition C-4 booster

Table No. 12

Test Configuration: Safe separation - 16 BLU hemispheres in 6061-T6 pouring trays on simulated belt conveyor with 2.0 kg flaked Composition B riser

Pouring tray - 385 mm square x 40 mm high x 8 mm thick

| Separation Distance (m) | Number of Tests | Number of Data Points | Number of Detonations | Number of Burns | Number of no Propagations | Percent No Detonations | Percent No Burns | Percent No Propagations |
|-------------------------|-----------------|-----------------------|-----------------------|-----------------|---------------------------|------------------------|------------------|-------------------------|
| 0                       | 14              | 28                    | 0                     | 0               | 28                        | 100                    | 100              | 100                     |
| 0.12                    | 2               | 4                     | 0                     | 0               | 4                         | 100                    | 100              | 100                     |
| 0.25                    | 2               | 4                     | 0                     | 0               | 4                         | 100                    | 100              | 100                     |
| 0.50                    | 1               | 2                     | 0                     | 0               | 2                         | 100                    | 100              | 100                     |

Donor initiated by a J-2 or M-6 electric blasting cap with 0.75 kg Composition C-4 booster

Table No. 13

Test Configuration: Safe separation - BLU hemispheres loose on simulated belt conveyor

| Separation Distance (m) | Number of Tests | Number of Data Points | Number of Detonations | Number of Burns | Number of no Propagations | Percent No Detonations | Percent No Burns | Percent No Propagations |
|-------------------------|-----------------|-----------------------|-----------------------|-----------------|---------------------------|------------------------|------------------|-------------------------|
| 0                       | 4               | 8                     | 3                     | 0               | 5                         | 62                     | 0                | 62                      |
| 0.013                   | 28              | 56                    | 0                     | 0               | 56                        | 100                    | 100              | 100                     |
| 0.025                   | 5               | 10                    | 0                     | 0               | 10                        | 100                    | 100              | 100                     |
| 0.051                   | 7               | 14                    | 0                     | 0               | 14                        | 100                    | 100              | 100                     |
| 0.076                   | 1               | 2                     | 0                     | 0               | 2                         | 100                    | 100              | 100                     |
| 0.152                   | 1               | 2                     | 0                     | 0               | 2                         | 100                    | 100              | 100                     |

Donor initiated with J-2 electric blasting cap with .011 kg Composition C-4 booster

Table No. 14

Test Configuration: Safe separation - BLU hemispheres in steel holding fixtures on a simulated belt conveyor

| Separation Distance (m) | Number of Tests | Number of Data Points | Number of Detonations | Number of Burns | Number of no Propagations | Percent No Detonations | Percent No Burns | Percent No Propagations |
|-------------------------|-----------------|-----------------------|-----------------------|-----------------|---------------------------|------------------------|------------------|-------------------------|
| 0.019*                  | 24              | 48                    | 0                     | 0               | 48                        | 100                    | 100              | 100                     |
| 0.025                   | 2               | 4                     | 0                     | 0               | 4                         | 100                    | 100              | 100                     |
| 0.051                   | 1               | 2                     | 0                     | 0               | 2                         | 100                    | 100              | 100                     |
| 0.076                   | 1               | 2                     | 0                     | 0               | 2                         | 100                    | 100              | 100                     |
| 0.102                   | 1               | 2                     | 0                     | 0               | 2                         | 100                    | 100              | 100                     |
| 0.152                   | 1               | 2                     | 0                     | 0               | 2                         | 100                    | 100              | 100                     |

Donor initiated by J-2 electric blasting cap with 0.011 kg Composition C-4 booster.

\* Minimum distance between hemispheres. Zero separation of steel holding fixtures.

Table No. 15

Test Configuration: Safe separation - assembled and fuzed BLU 63 A/B bomblets  
on simulated belt conveyor

| Separation<br>Distance<br>(m) | Number<br>of<br>Tests | Number<br>of<br>Data<br>Points | Number<br>of<br>Detonations | Number<br>of<br>Burns | Number<br>of no<br>Propagations | Percent<br>No<br>Detonations | Percent<br>No<br>Burns | Percent<br>No<br>Propagations |
|-------------------------------|-----------------------|--------------------------------|-----------------------------|-----------------------|---------------------------------|------------------------------|------------------------|-------------------------------|
| 0                             | 1                     | 2                              | 2                           | 0                     | 0                               | 0                            | -                      | 0                             |
| 0.013                         | 7                     | 14                             | 3                           | 8                     | 3                               | 78                           | 43                     | 21                            |
| 0.025                         | 23                    | 46                             | 0                           | 0                     | 46                              | 100                          | 100                    | 100                           |
| 0.051                         | 25                    | 50                             | 0                           | 1                     | 49                              | 100                          | 98                     | 98                            |
| 0.076                         | 1                     | 2                              | 0                           | 0                     | 2                               | 100                          | 100                    | 100                           |
| 0.102                         | 1                     | 2                              | 0                           | 0                     | 2                               | 100                          | 100                    | 100                           |
| 0.152                         | 1                     | 2                              | 0                           | 0                     | 2                               | 100                          | 100                    | 100                           |

Donor initiated by J-2 or M-6 electric blasting cap with 0.036 kg Composition C-4 booster.



Table 16. Characteristic distances (dimensionless)

| Symbol <sup>(1)</sup> | No Detonation |                 | No Burn |           | No Propagation |           | $\frac{C}{M}$ <sup>(3)</sup> |
|-----------------------|---------------|-----------------|---------|-----------|----------------|-----------|------------------------------|
|                       | $X_0^{(2)}$   | $X_{100}^{(2)}$ | $X_0$   | $X_{100}$ | $X_0$          | $X_{100}$ |                              |
| ○                     | 0.019         | 0.048           | 0.024   | 0.054     | 0.019          | 0.054     | 0.61                         |
| ●                     | -0.0023       | 0.033           | --      | --        | -0.0023        | 0.033     | 0.54                         |
| □                     | --            | --              | 0.3078  | 0.920     | 0.3078         | 0.920     | 0.95                         |
| ▽                     | --            | --              | 1.198   | 2.421     | 1.198          | 2.421     | 15.22                        |
| ■                     | 0.810         | 1.824           | 0.810   | 2.200     | 0.810          | 2.200     | 15.22                        |
| △                     | 0.871         | 1.915           | 0.871   | 1.915     | 0.871          | 1.915     | 15.22                        |
| ▲                     | 2.406         | 3.018           | 2.406   | 3.018     | 2.406          | 3.018     | 6.37                         |
| ◇                     | 2.712         | 3.018           | 2.712   | 3.018     | 2.712          | 3.018     | 6.37                         |
| ◆                     | --            | --              | 1.198   | 2.421     | 1.198          | 2.421     | 19.57                        |

(1) See legend in Figures 32, 33 and 34 for descriptions of symbols.

(2) See equation (1) for definition of  $X_0$  and  $X_{100}$ . (See page 11)

(3) Charge to mass ratio.

Table 17

Safe separation distances found to be adequate  
by the testing program

| CONFIGURATION                                     | TYPE<br>CONVEYANCE       | SEPARATION<br>DISTANCE | REMARKS   |
|---|--------------------------|------------------------|---|
| 27.3 kg Cyclotol<br>in Cardboard<br>Containers    | Steel Roller<br>Conveyor | 5.5 m                  | Shielded by 9<br>mm thick Kevlar<br>bounded to<br>Container<br><br>Provided Riser<br>is limited to<br>20 kg of Explo-<br>sive |
| 27.3 kg Cyclotol<br>in Aluminum (1)<br>Containers | Pendant Type<br>Conveyor | 7.3 m                  |   |
| 16 BLU Hemis-<br>pheres in<br>Pouring Trays       | Belt<br>Conveyor         | 0                      |   |
| Loose<br>Hemispheres                              | Belt<br>Conveyor         | 13 mm                  |   |
| Hemispheres in<br>Holding<br>Fixtures             | Belt<br>Conveyor         | 0                      |   |
| Complete<br>Bomblets<br>with Fuze<br>Assembly     | Belt<br>Conveyor         | 25 mm                  |   |

(1) Type 7075-T6

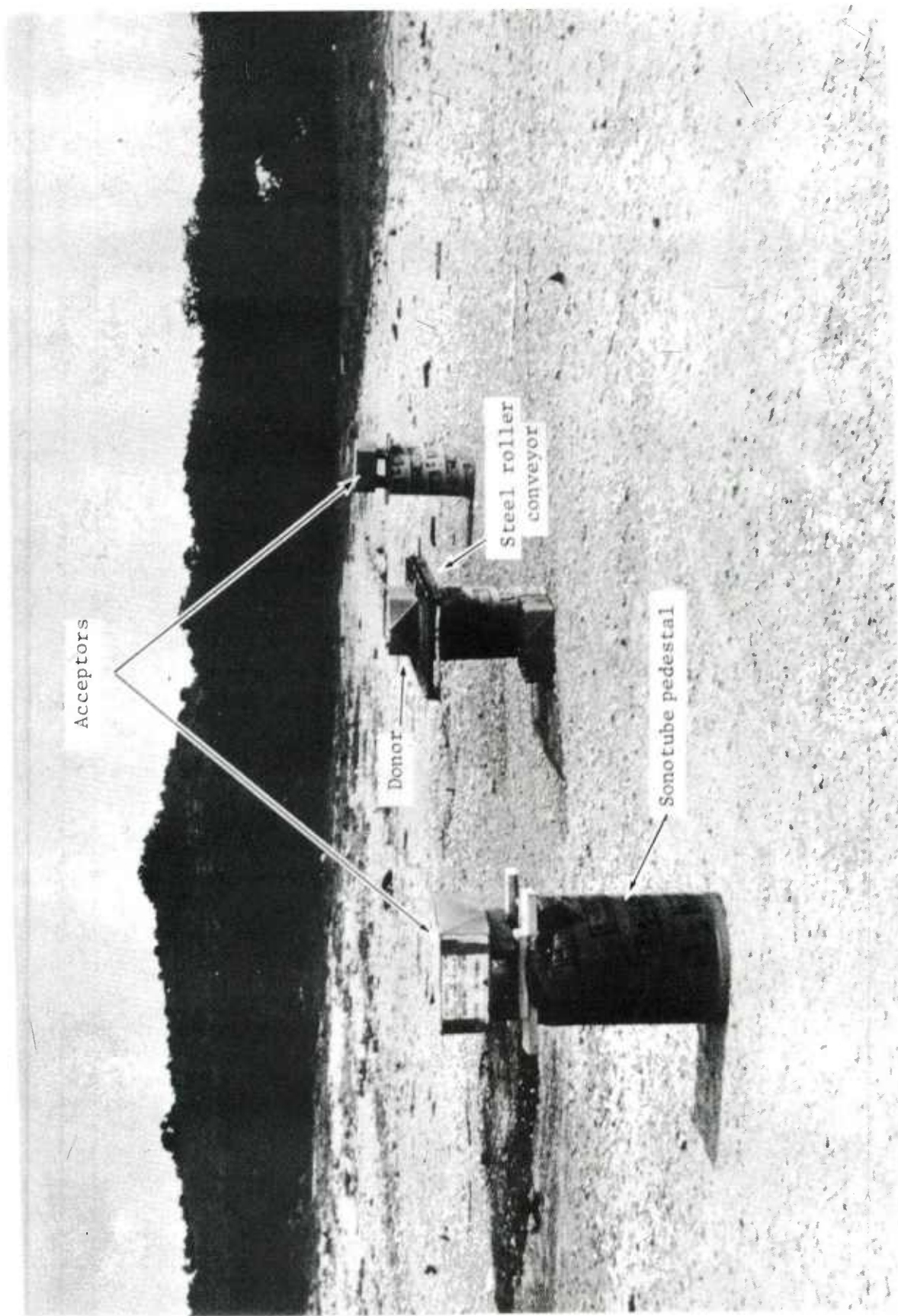


FIGURE 1. TYPICAL TEST SET-UP SAFE SEPARATION 27.3 kg CYCLOTOL ON STEEL ROLLER CONVEYOR

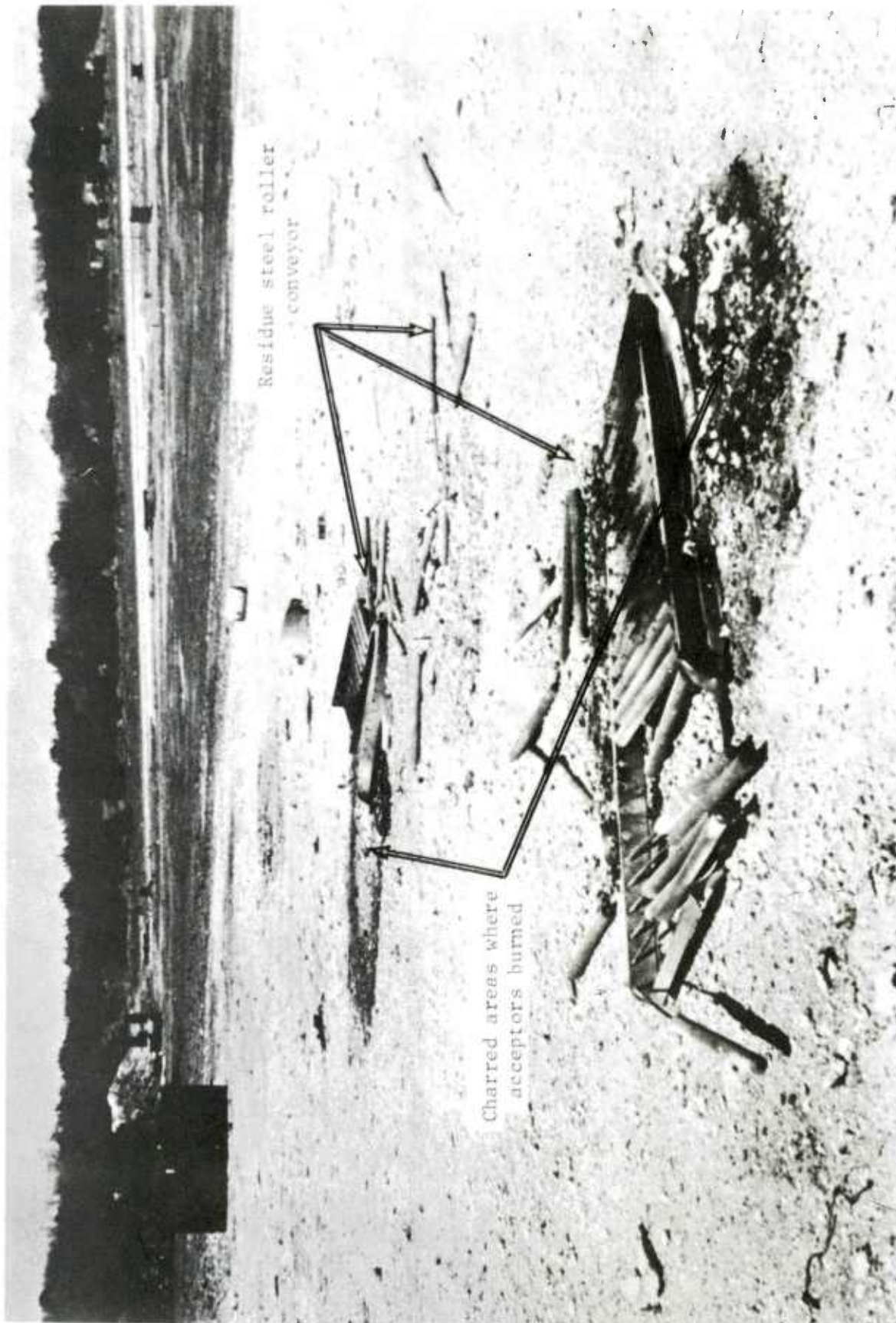


FIGURE 2. RESULTS OF PROPAGATION BY BURNING - SAFE SEPARATION 27.3 kg  
CYCLOTOL ON STEEL ROLLER CONVEYOR (3.7 METERS)





FIGURE 3. TYPICAL DAMAGE SUSTAINED BY ACCEPTORS WHICH DID NOT PROPAGATE AT 3.7 AND 4.6 METERS SEPARATION

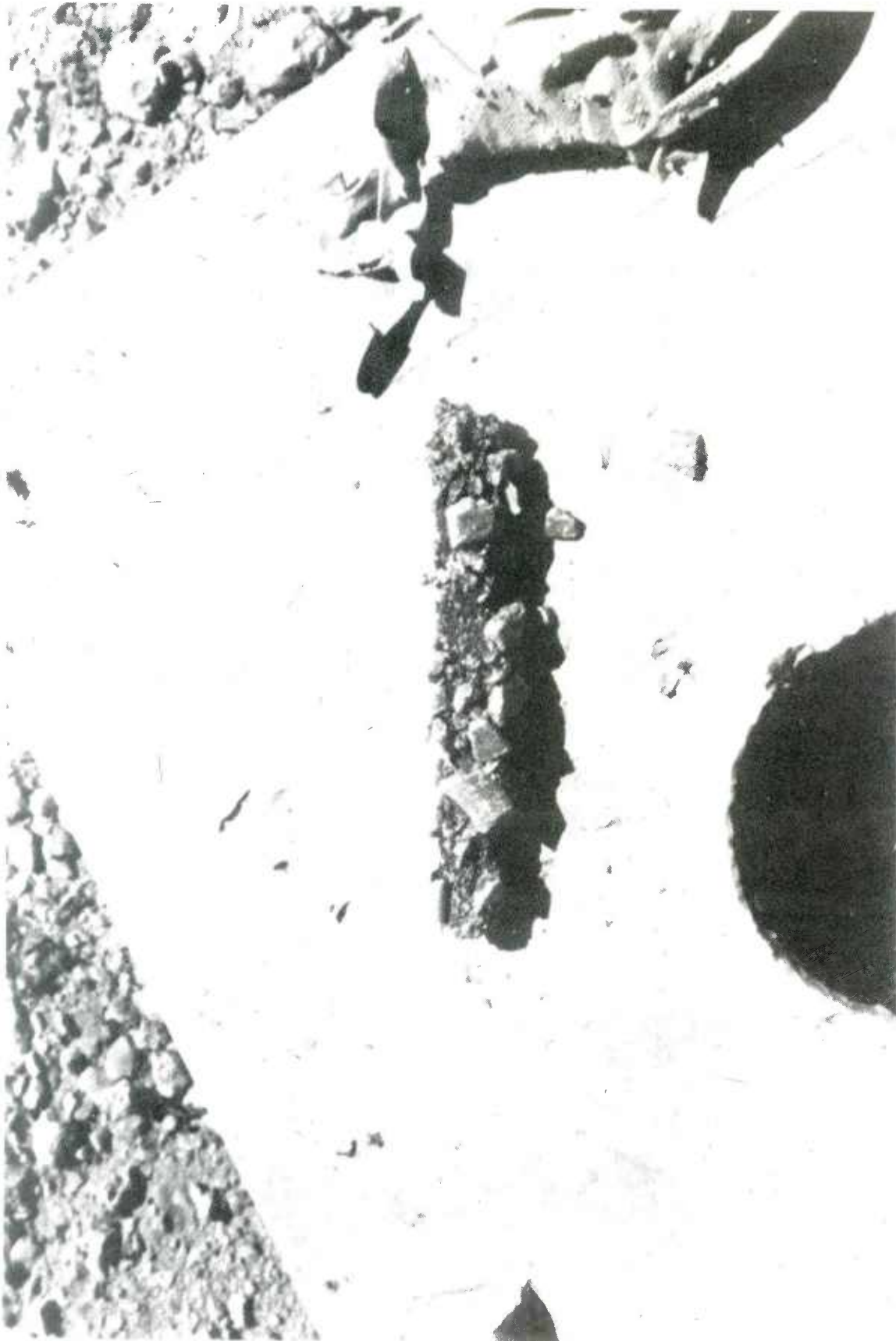


FIGURE 4. FRAGMENT OF ROLLER CONVEYOR RECOVERED FROM ACCEPTOR, ENCRUSTED WITH CYCLOTOL (3.7 METERS)

Large steel  
fragment

Small steel  
fragment

FIGURE 5. FRAGMENTS RECOVERED FROM ACCEPTOR RESIDUE WHICH PROPAGATED BY  
BURNING (3.7 AND 4.6 METERS)



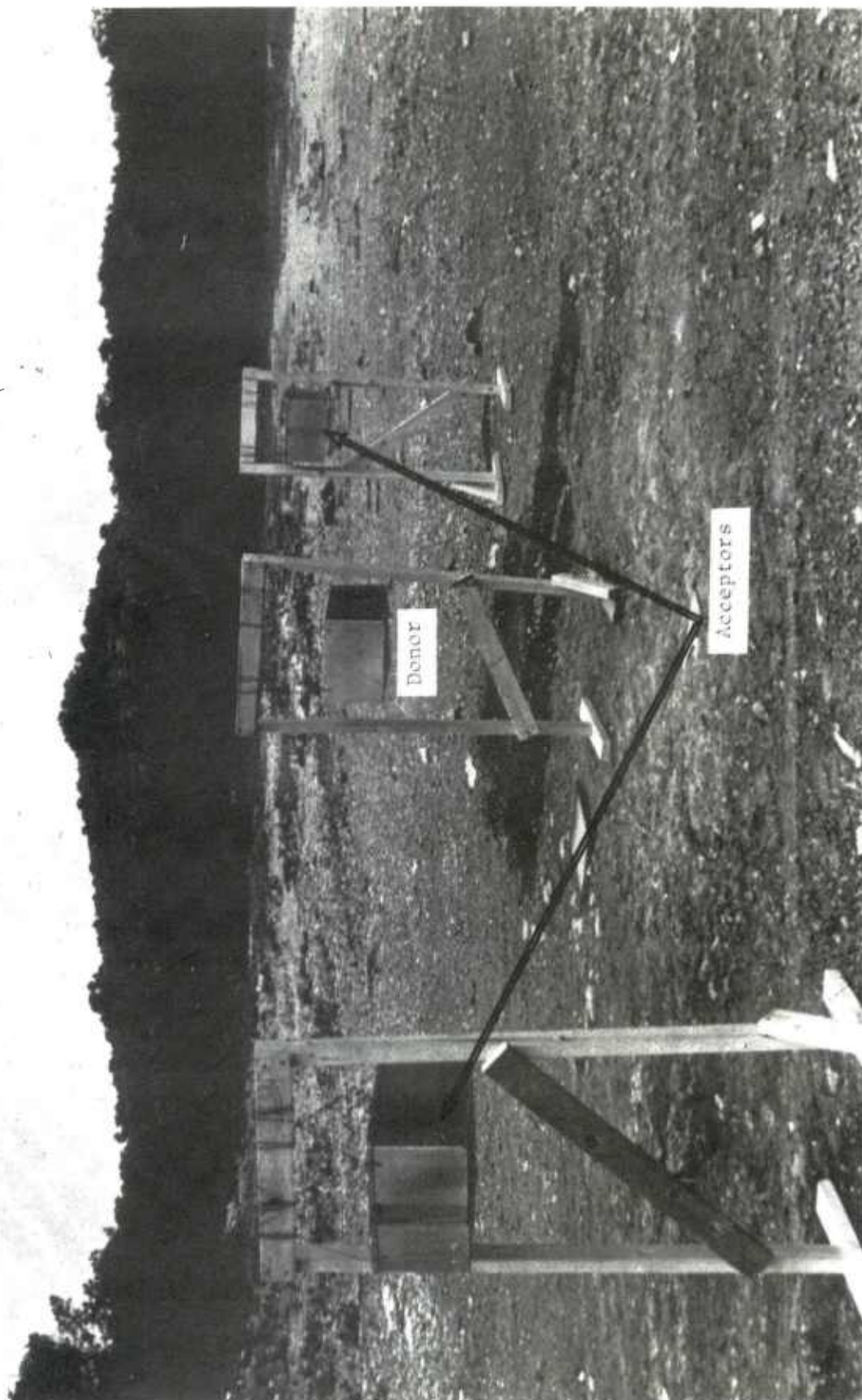


FIGURE 6. TYPICAL TEST SET-UP - SAFE SEPARATION 27.3 kg CYCLOTOL IN 6061-T6 ALUMINUM BOXES, 3 MM THICK, SUSPENDED PENDANT STYLE

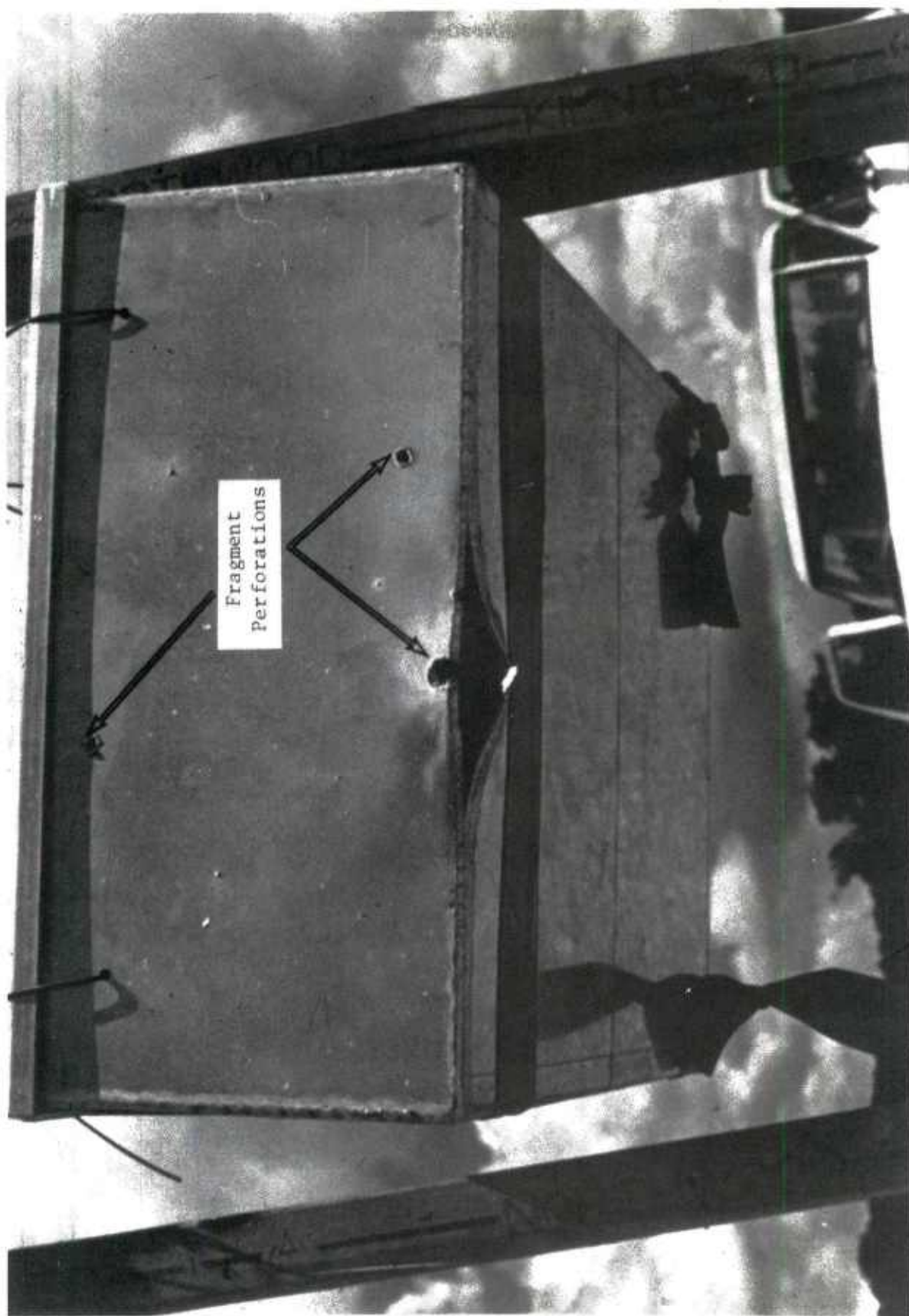


FIGURE 7. FRAGMENT PENETRATIONS OF 6061-T6 ALUMINUM (3 MM THICK) BOX  
AT 9.1 METERS SEPARATION



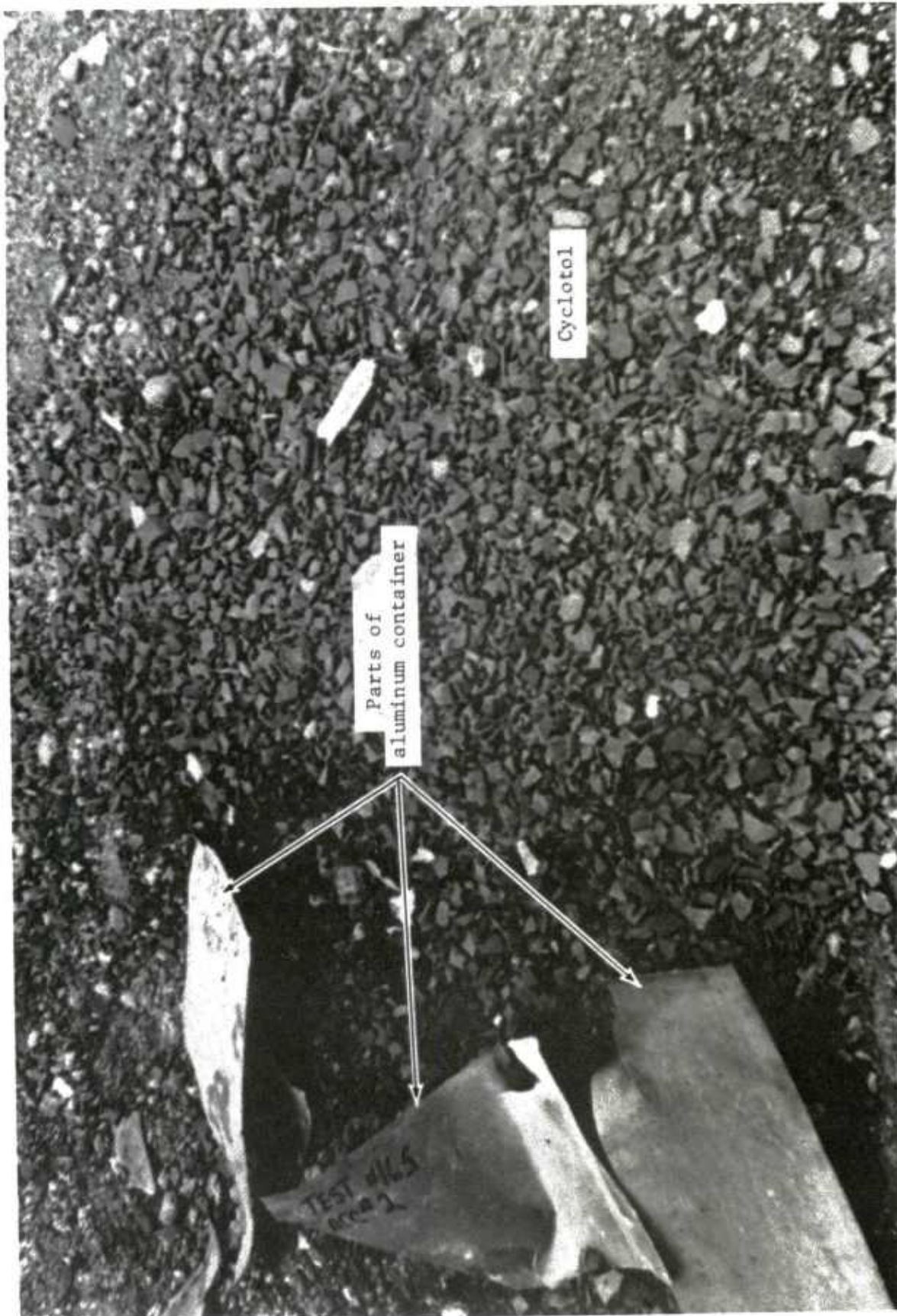


FIGURE 8. DAMAGED SUSPENDED BY 6061-T6 (1 MM THICK) ALUMINUM BOX SUSPENDED  
PENDANT STYLE AT 3.7 METERS SEPARATION (NOTE THE CYCLOTOL STREWN  
ON THE GROUND)



FIGURE 9. PERFORATIONS BY FRAGMENTS ON FACE OF ACCEPTOR FACING DONOR  
(6061-T6 [1 MM THICK] ALUMINUM)



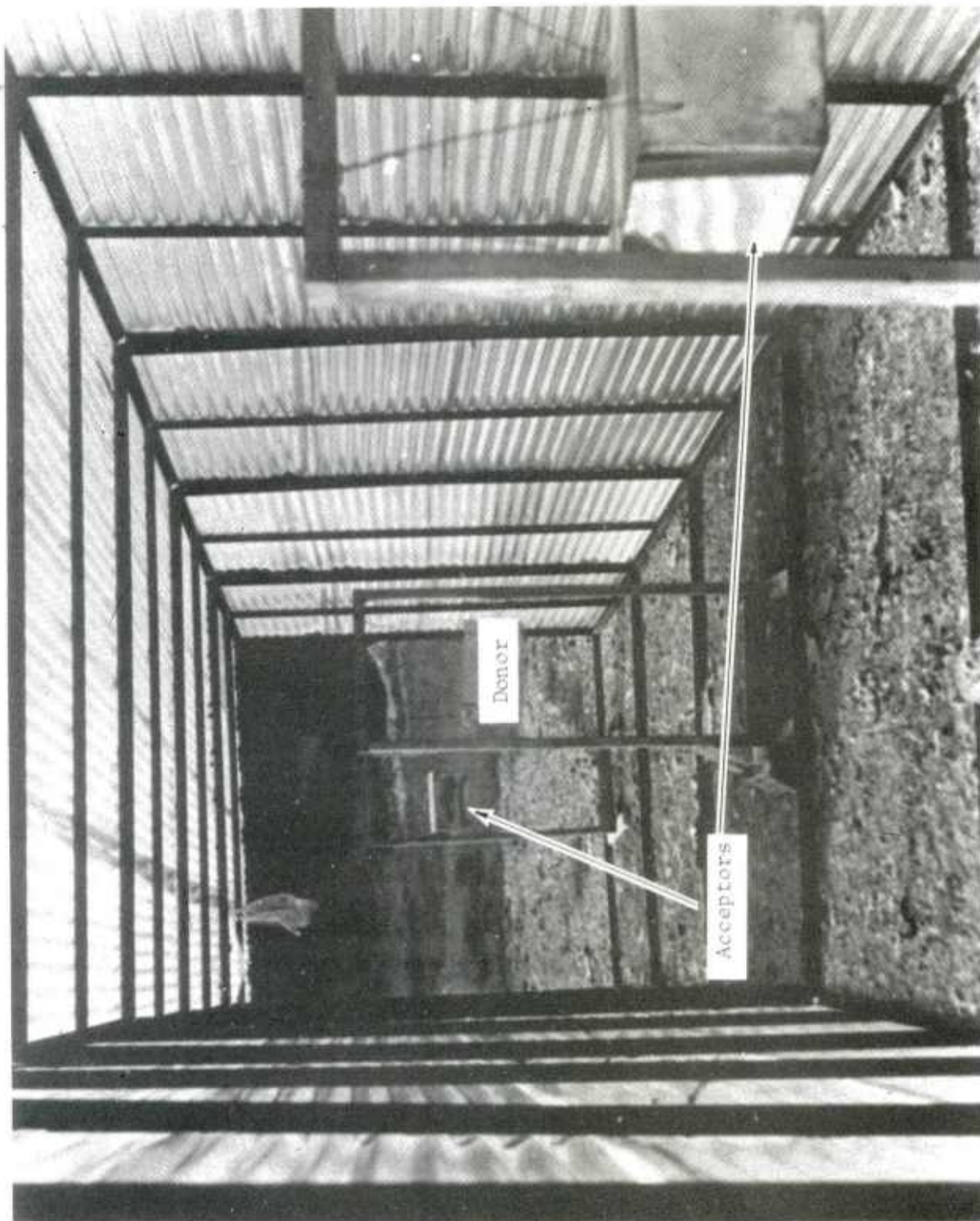


FIGURE 10. TYPICAL EXPERIMENTAL SET-UP FOR SAFE SEPARATION TEST OF 27.3 kg CYCLOTOL IN ALUMINUM BOXES (7075-T6 1 MM THICK) IN TUNNEL

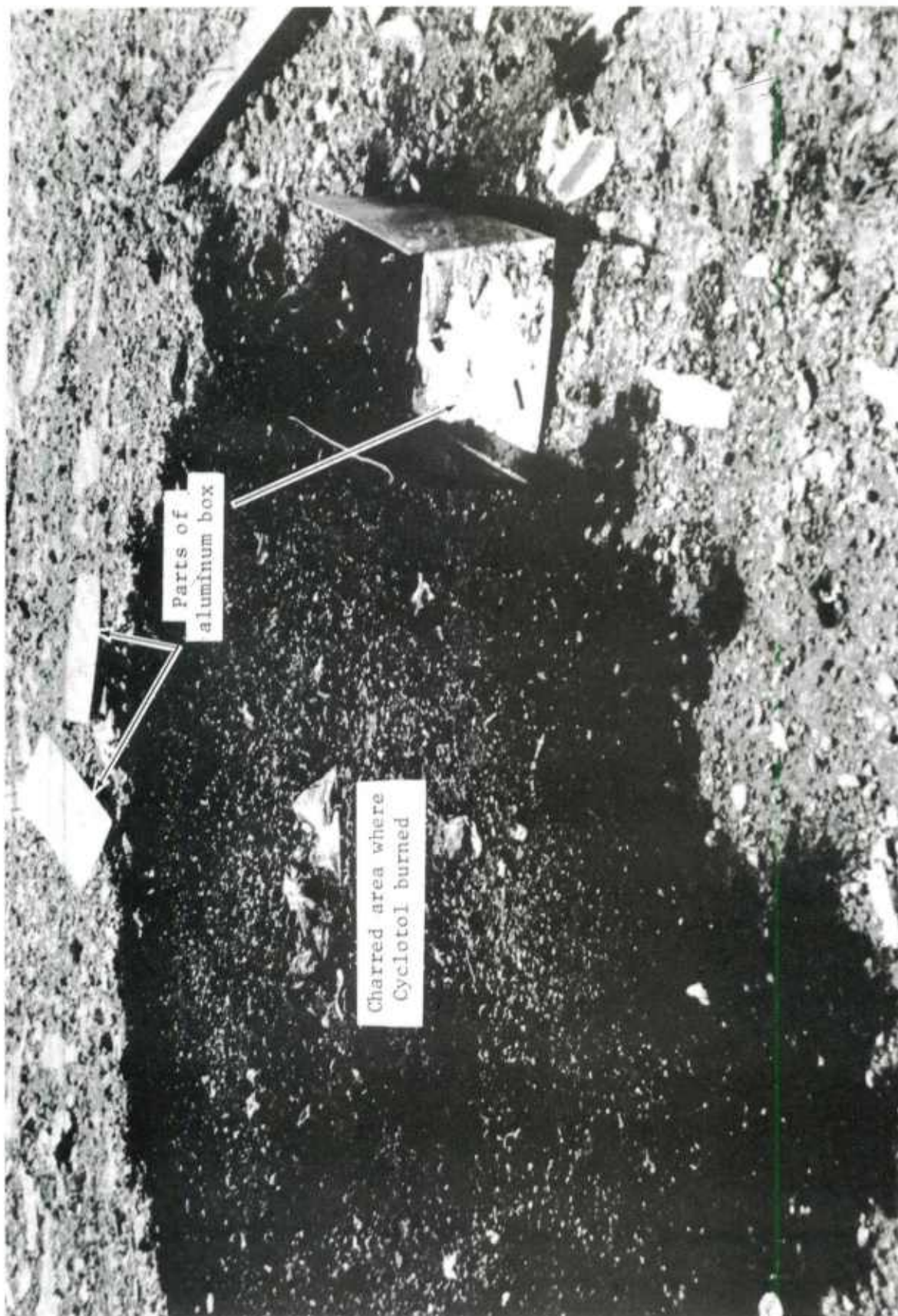


FIGURE 11. RESIDUE FROM ACCEPTOR THAT BURNED - SAFE SEPARATION - 27.3 kg CYCLOFOL IN 7075-T6 (1 MM THICK) ALUMINUM BOXES SUSPENDED PENDANT STYLE IN TUNNEL (5.5 METERS)





FIGURE 12. SCATTERED CYCLOTOL FROM ACCEPTOR THAT DID NOT PROPAGATE

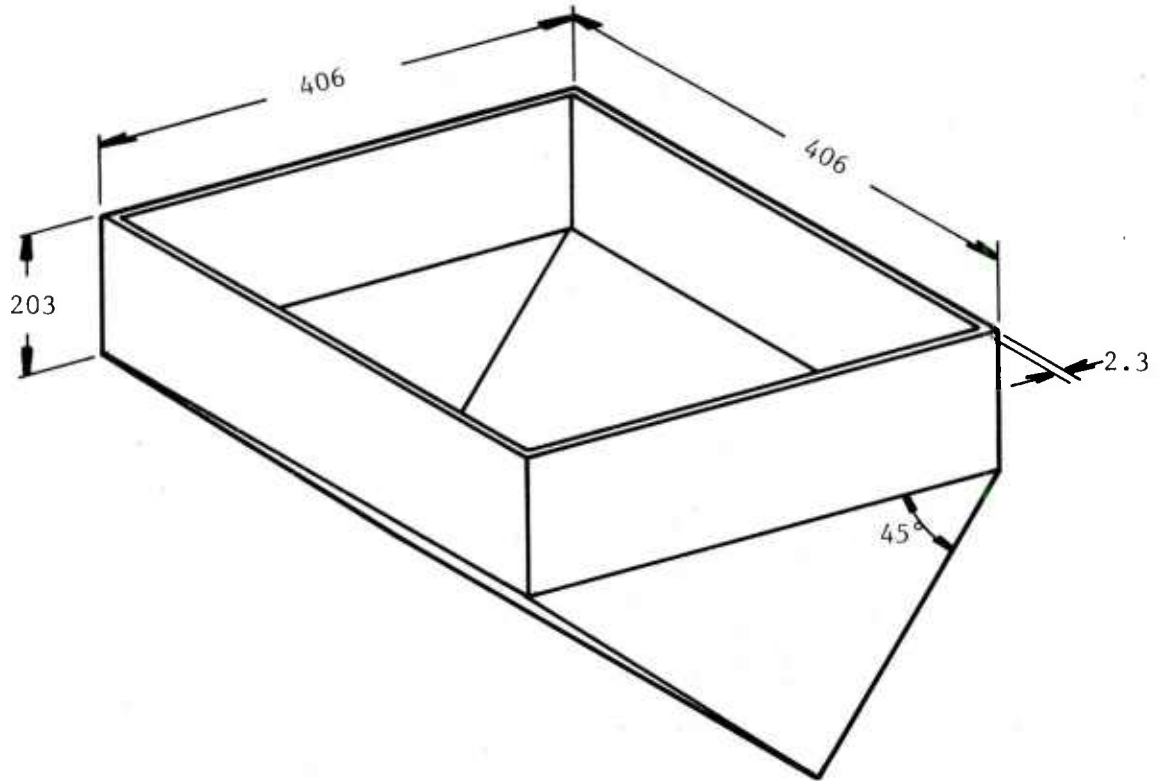




FIGURE 13. EXPERIMENTAL SET-UP TO TEST FEASIBILITY OF STEEL SHIELDING BETWEEN 7075-T6 ALUMINUM CONTAINERS OF CYCLOTOL



FIGURE 14. DAMAGE SUSTAINED BY 3.2 MM STEEL SHIELD SUSPENDED 1.8 METERS  
FROM 27.3 kg OF CYCLOTOL IN 7075-T6 ALUMINUM CONTAINER



● Dimensions in mm

FIGURE 15. 7075-T6 ALUMINUM CONTAINERS SPECIFIED BY USER AGENCY



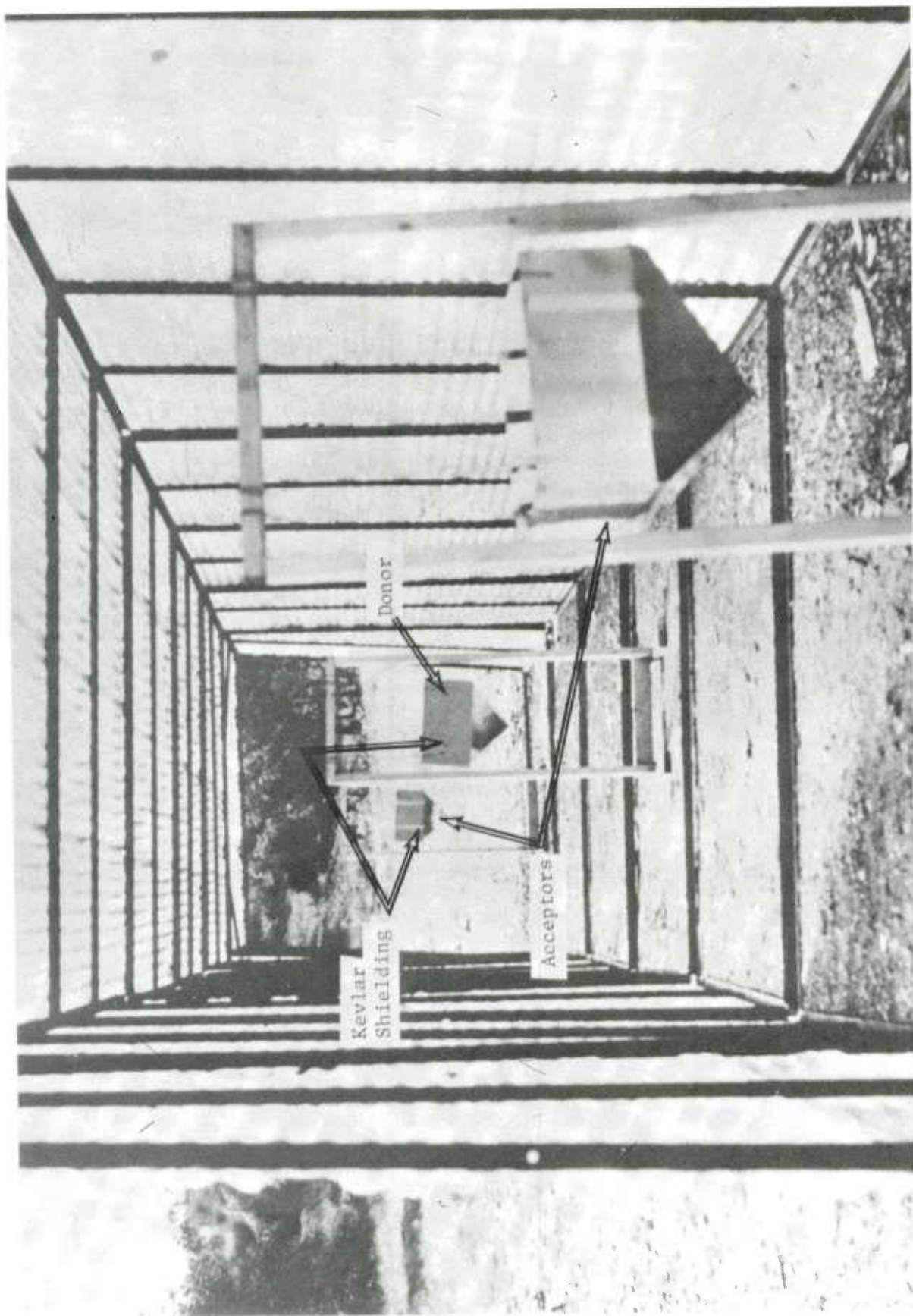


FIGURE 16. TYPICAL EXPERIMENTAL SET-UP FOR 27.3 kg OF CYCLOTOL IN 7075-T6 ALUMINUM CONTAINERS WITH 9.5 MM KEVLAR SHIELDING

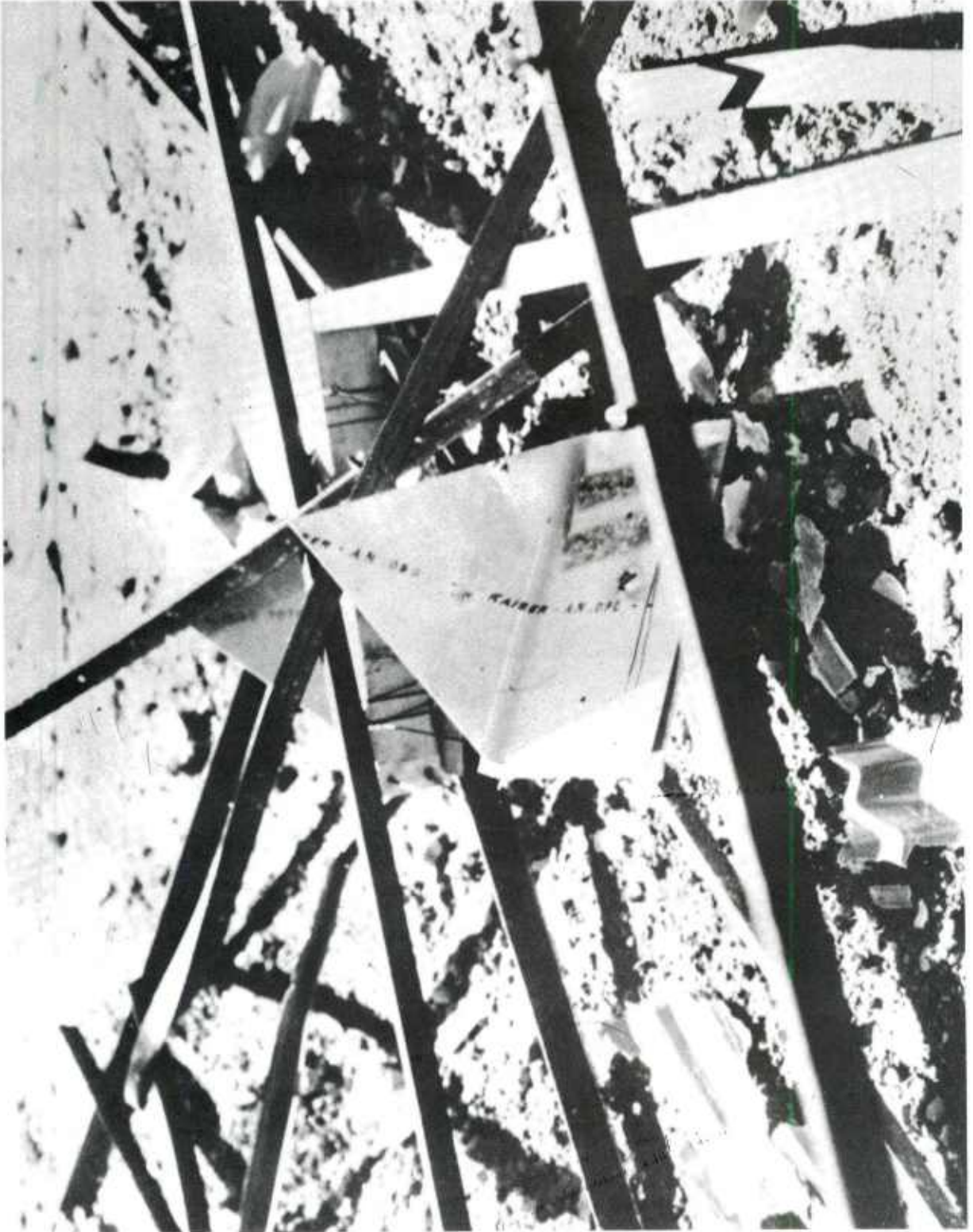


FIGURE 17. TYPICAL CONDITION OF THE ACCEPTORS AFTER THE DETONATION OF THE DONOR CHARGE



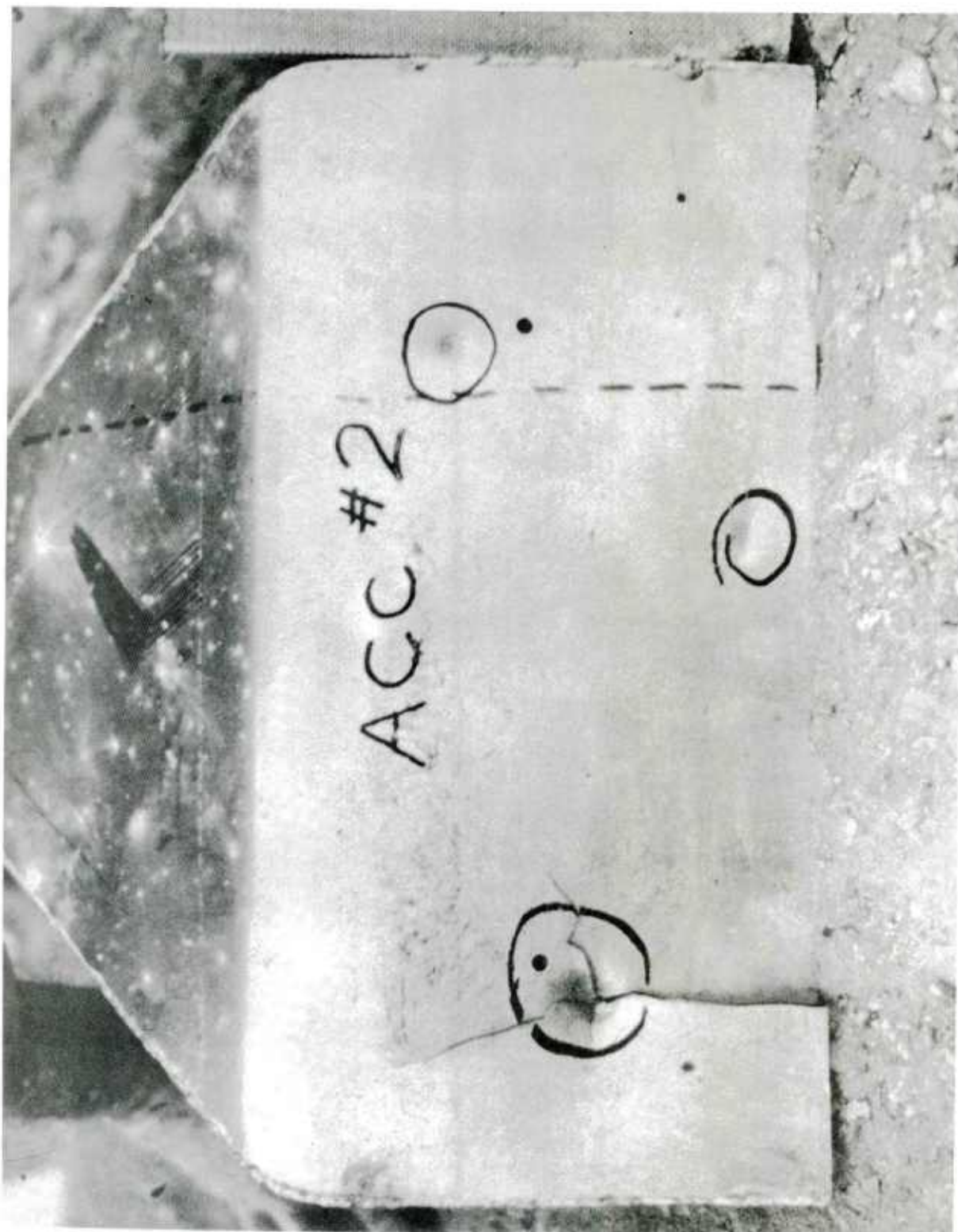


FIGURE 18. CONDITION OF THE 7075-T6 ALUMINUM CONTAINER WITH THE KEVLAR SHIELD REMOVED (NOTE: FACING DENTED & CRACKED, NO PERFORATIONS)

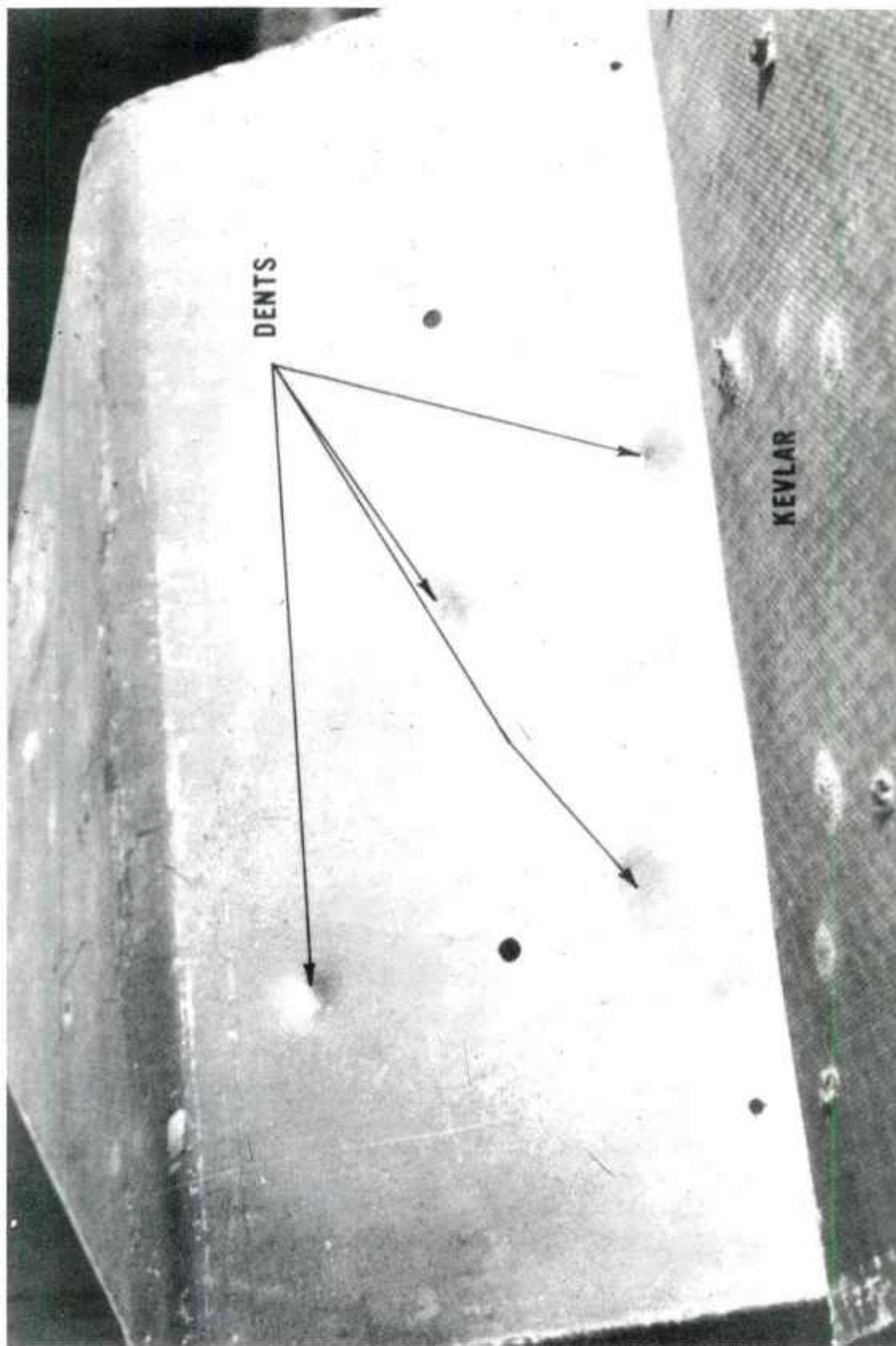


FIGURE 19. TYPICAL DAMAGE TO THE ALUMINUM WALL OF A 2.3 mm THICK 7075-T6 ALUMINUM ACCEPTOR SHIELDED BY 9.5 mm OF KEVLAR AT 7.3 m SEPARATION.



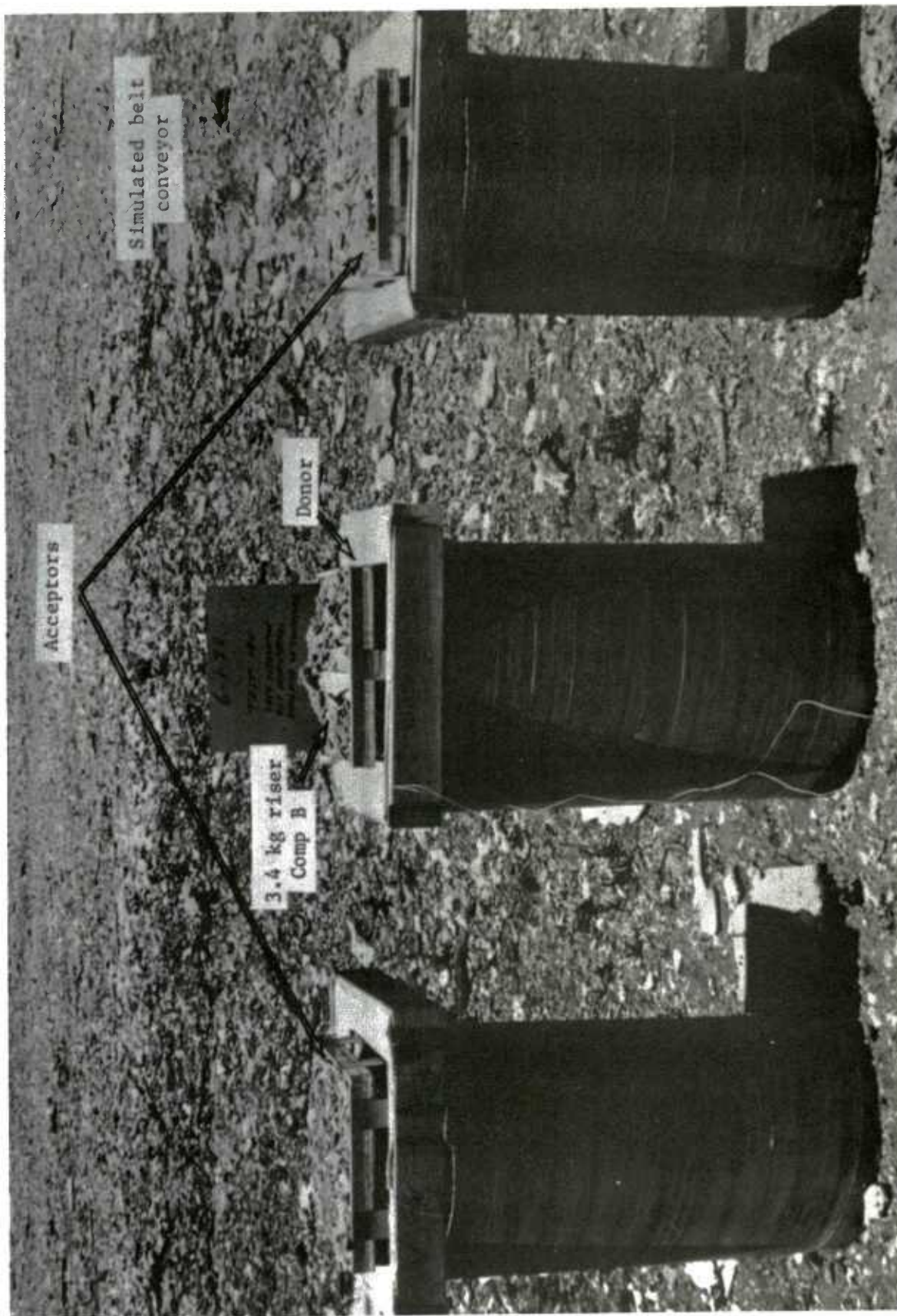


FIGURE 20. TYPICAL SET-UP - BLU HEMISPHERES IN POURING TRAYS - 3.4 kg RISER

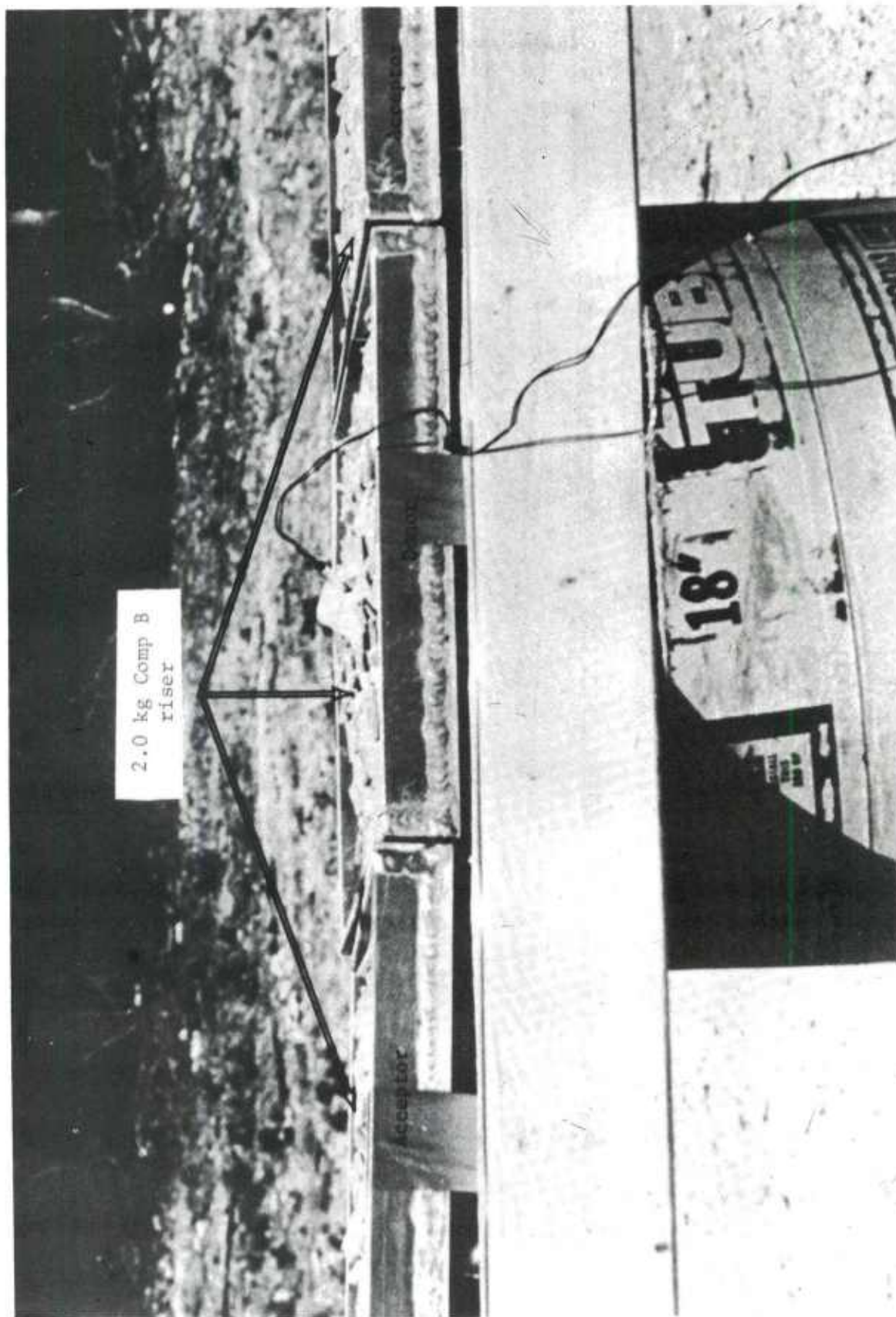


FIGURE 21. EXPERIMENTAL SET-UP - SAFE SEPARATION BLU HEMISPHERES IN POURING TRAYS WITH 2.0 kg OF COMPOSITION B IN RISERS (0 METER SEPARATION.)



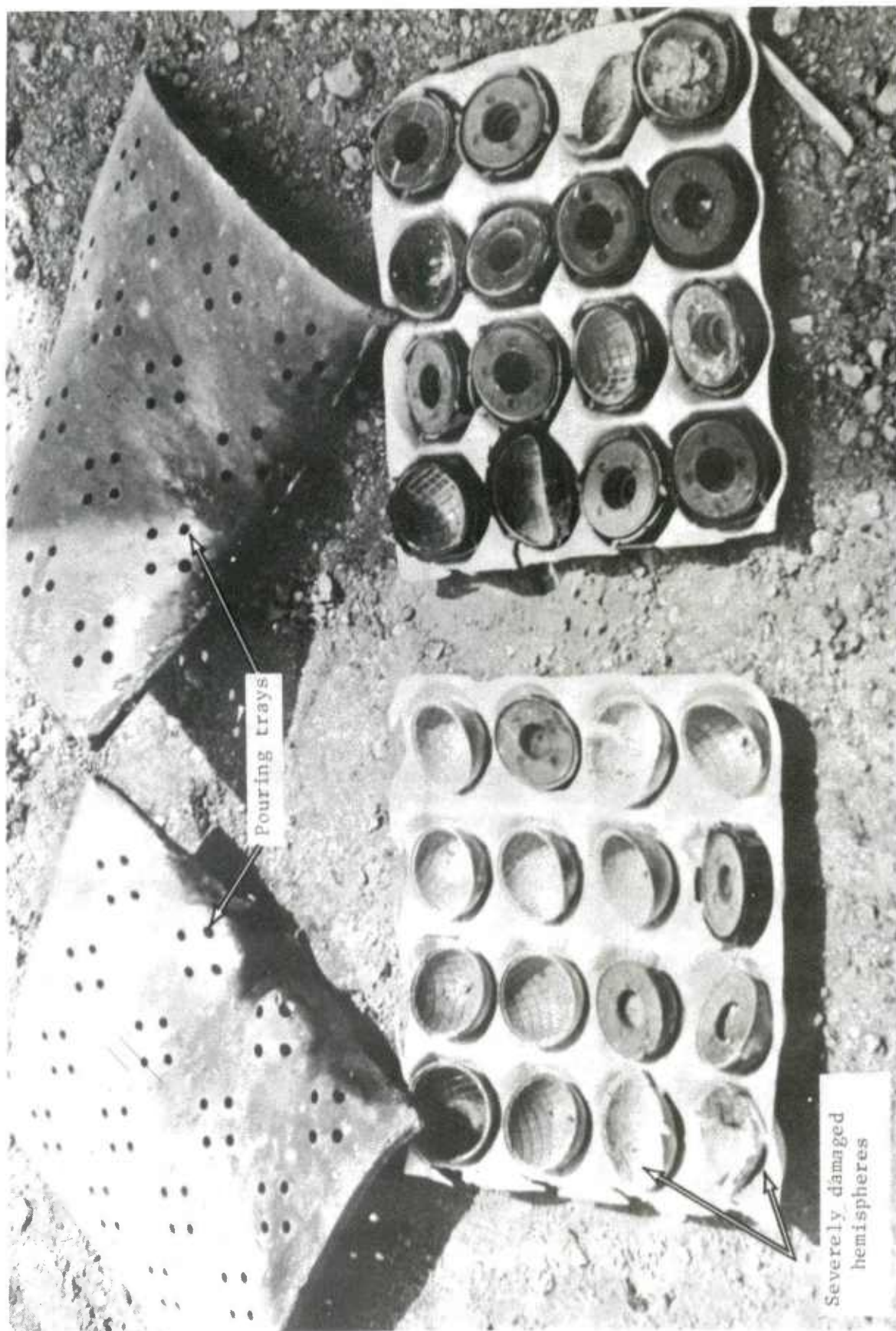


FIGURE 22. RESIDUE RECOVERED FROM SAFE SEPARATION TEST OF 2.0 kg COMP B RISER AT 0 METER SEPARATION (NOTE THE VARIANCE OF DAMAGE TO HEMISPHERES; SEVERE TO MILD)

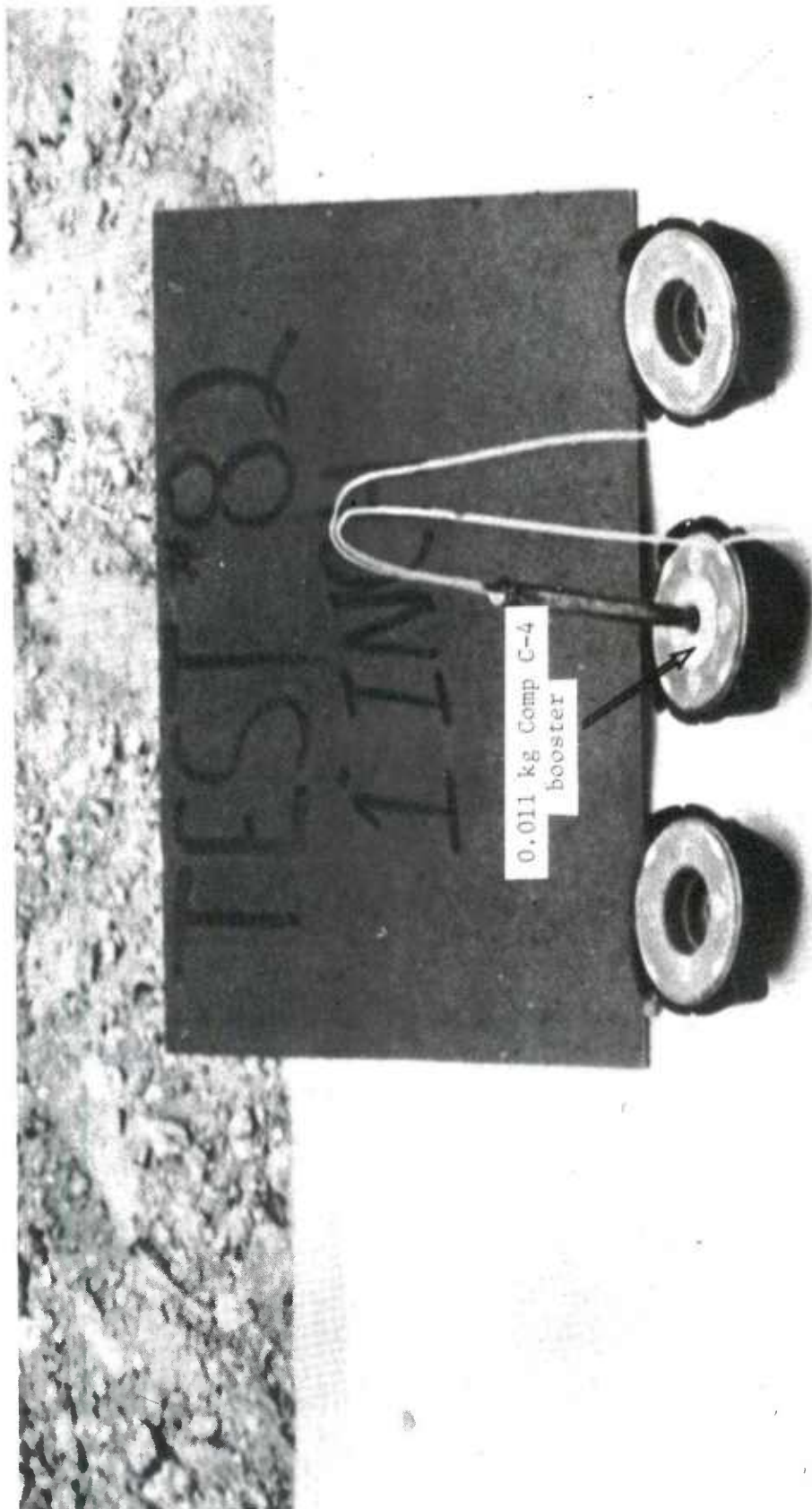


FIGURE 23. SAFE SEPARATION TEST OF BLU 63 HEMISPHERES 25.4 MM SPACING  
ON CANVAS CONVEYOR

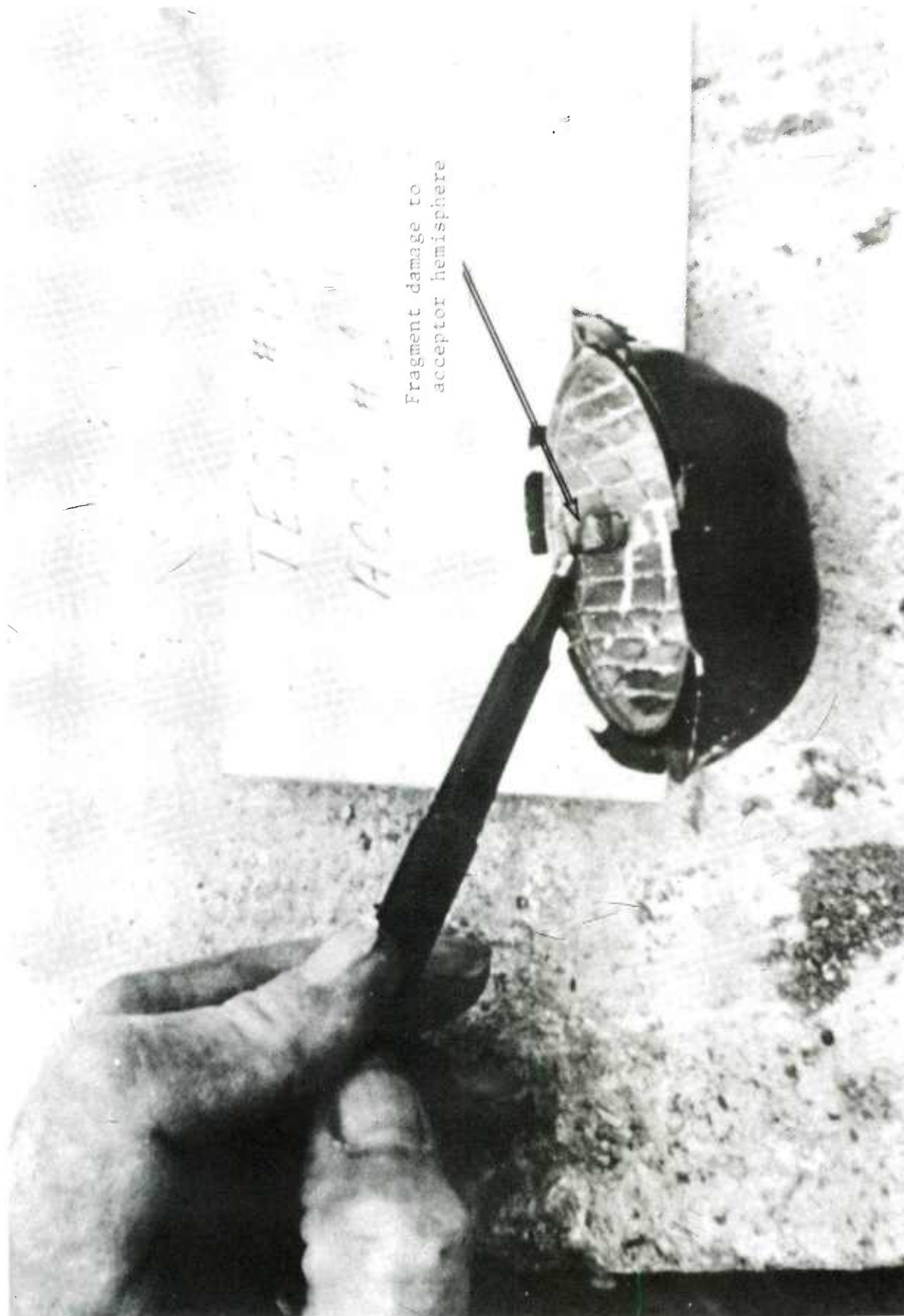


FIGURE 24. BLU 63 HEMISPHERE RECOVERED FROM SAFE SEPARATION TEST  
(50.8 MM SEPARATION)



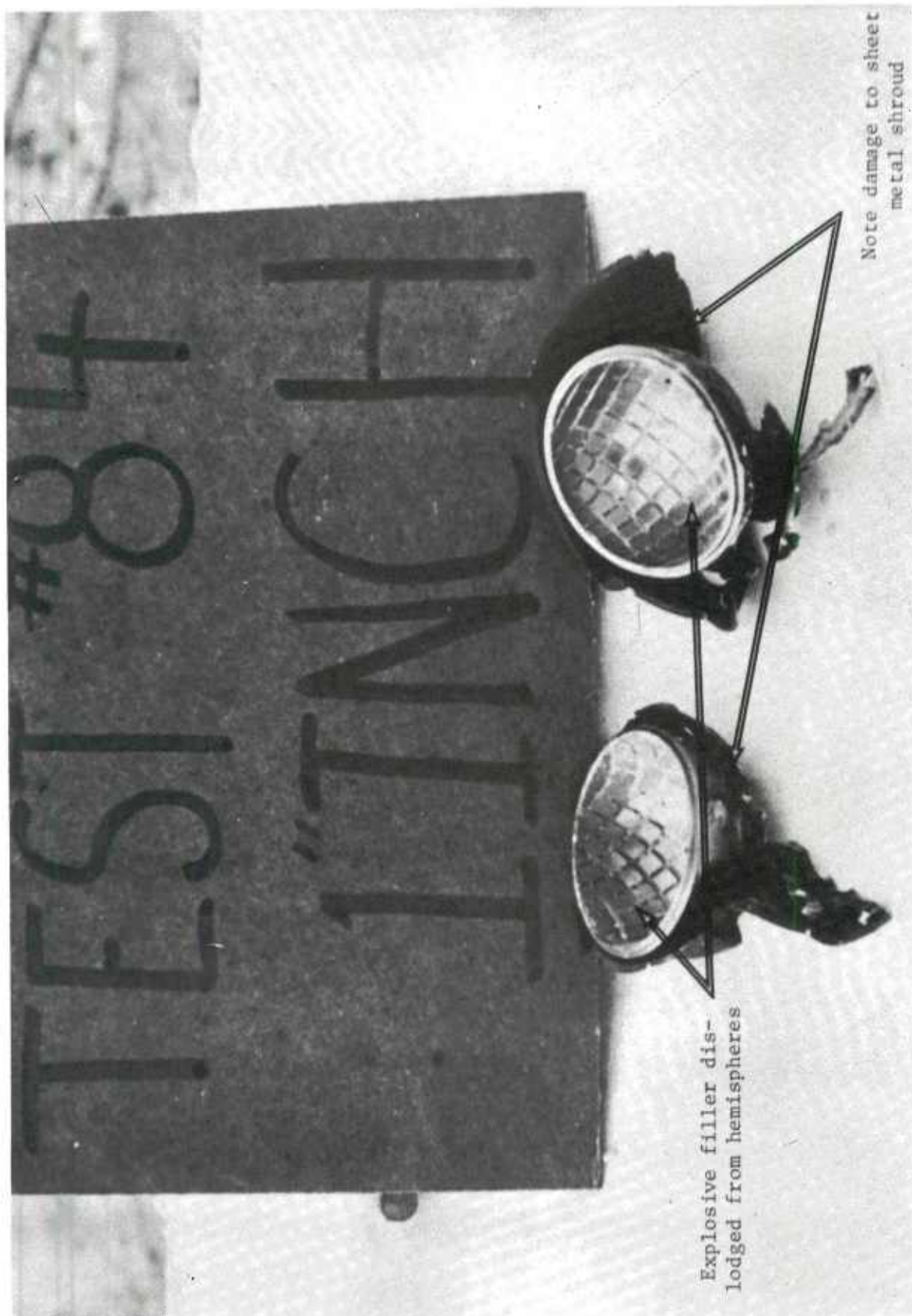


FIGURE 25. BLU 63 HEMISPHERES RECOVERED FROM SAFE SEPARATION TEST  
(25.4 MM SEPARATION)

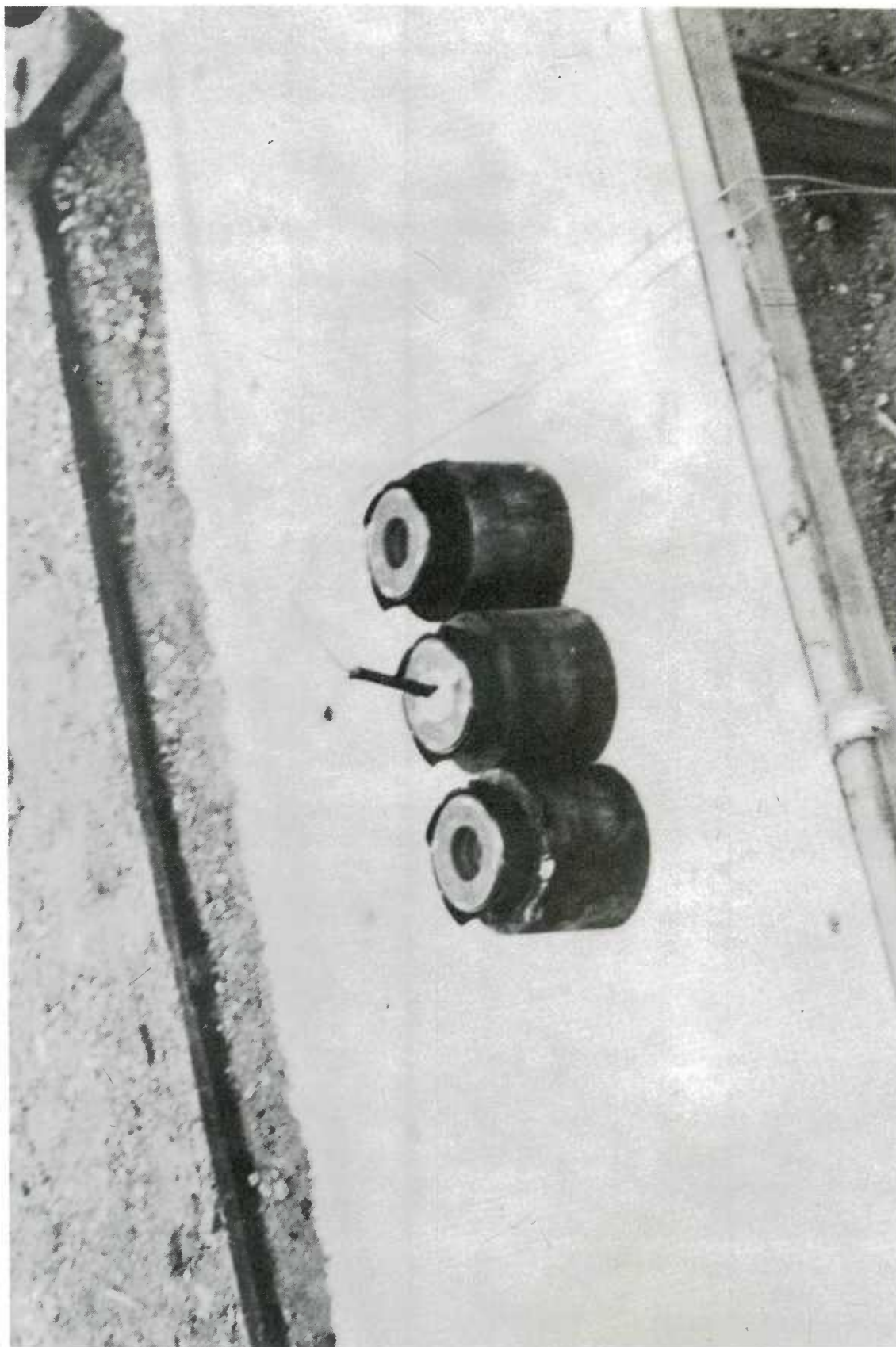


FIGURE 26. SAFE SEPARATION SET-UP FOR BLU 63 HEMISPHERES IN STEEL HOLDING  
FIXTURES (FIXTURES TOUCHING)



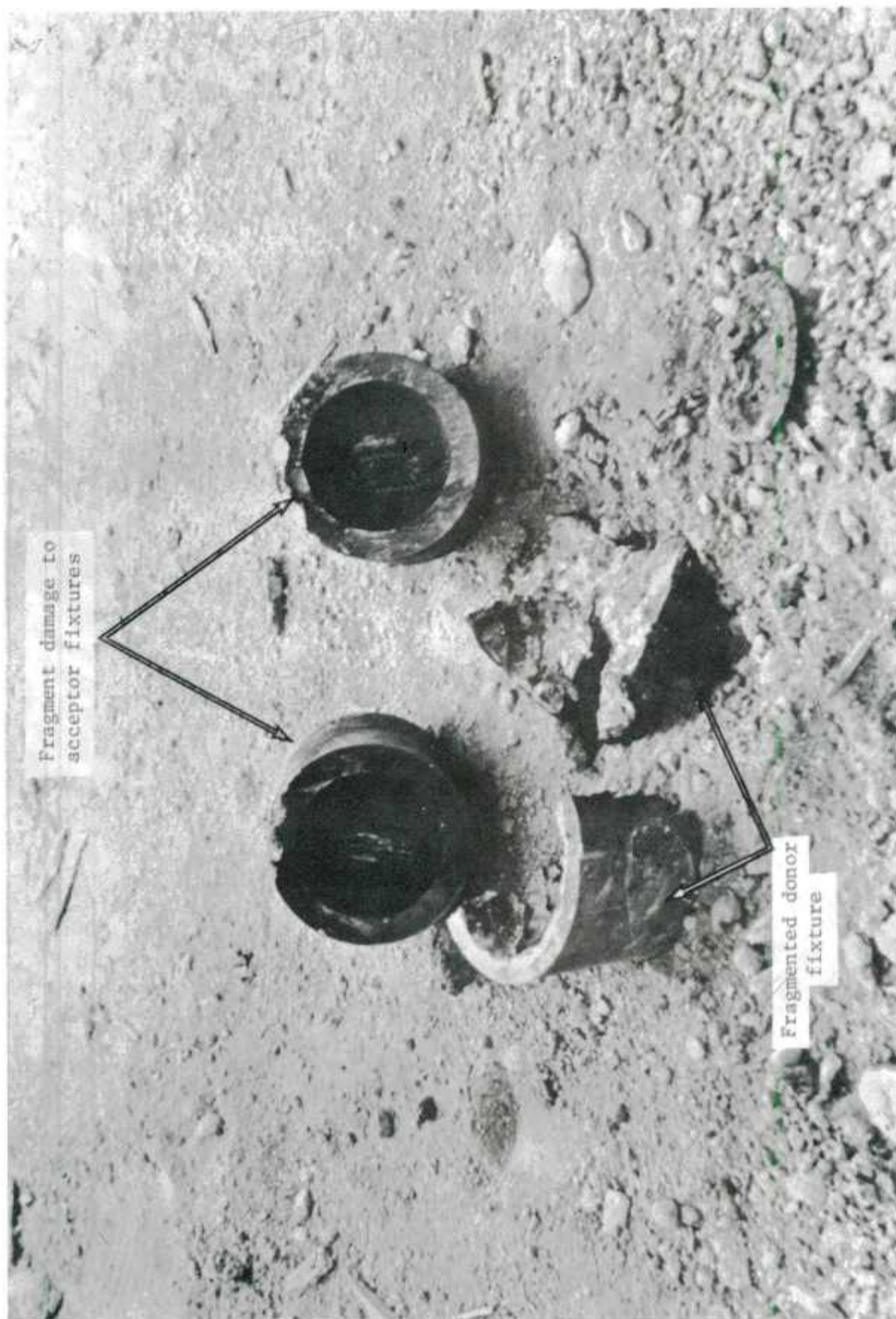


FIGURE 27. TYPICAL RESIDUE RECOVERED FROM SAFE SEPARATION TESTS BLU 63  
HEMISPHERES IN STEEL HOLDING FIXTURES (FIXTURES TOUCHING)

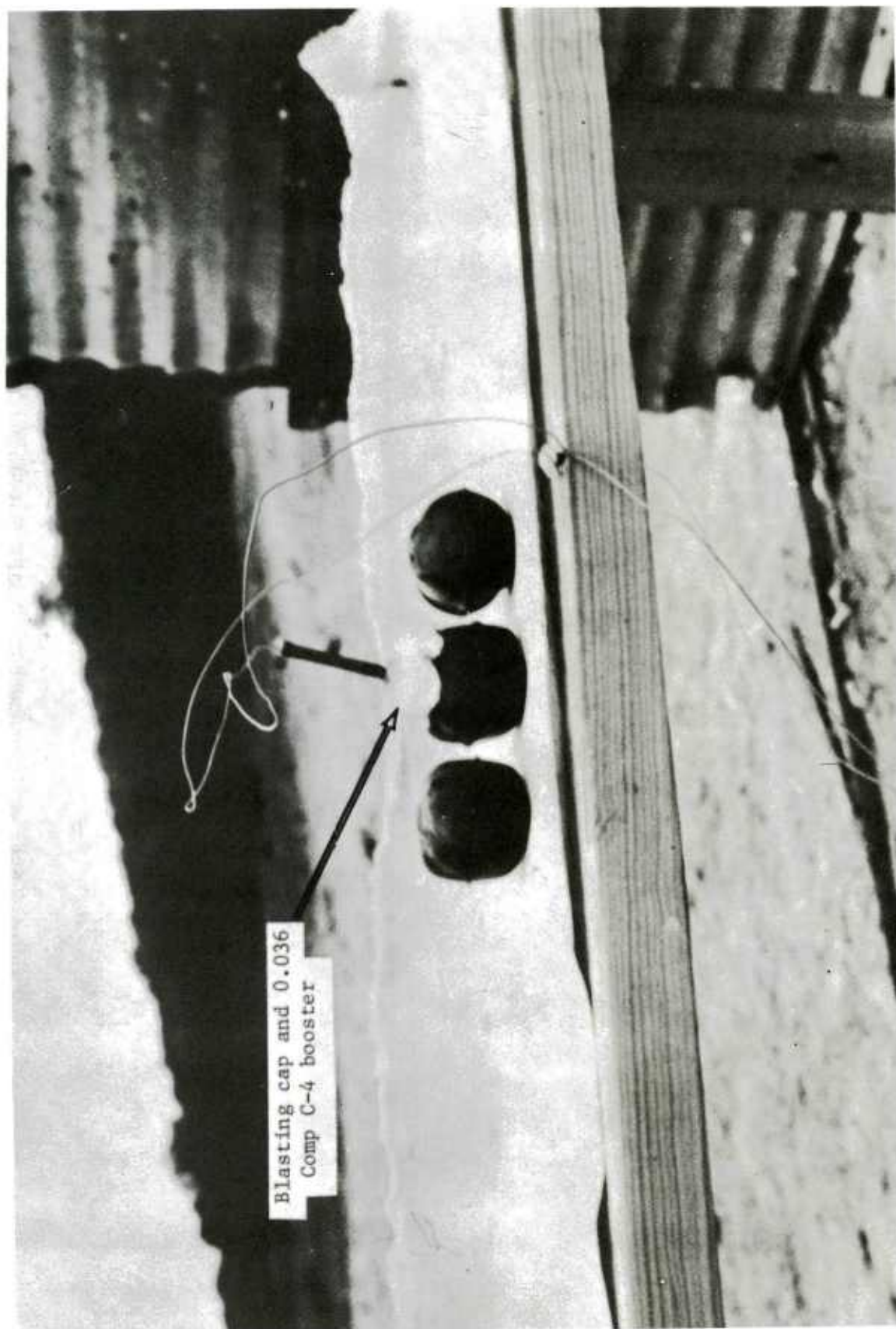


FIGURE 28. TYPICAL TEST SET-UP FOR SAFE SEPARATION OF BLU 63 BOMBLETS  
(25.4 MM SEPARATION)



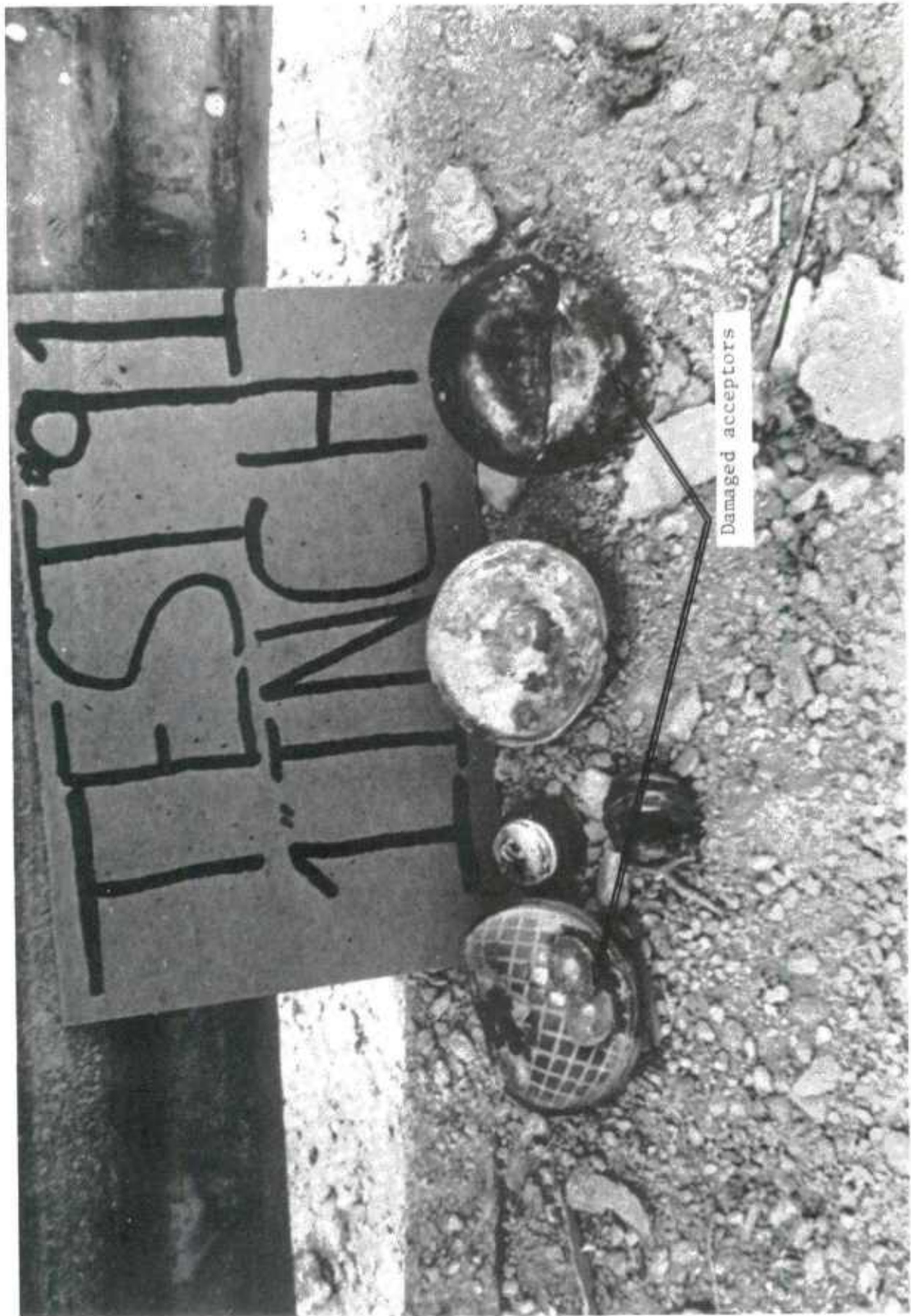


FIGURE 29. TYPICAL RESULTS OF SAFE SEPARATION OF BLU 63 BOMBLET  
(25.4 MM SEPARATION)

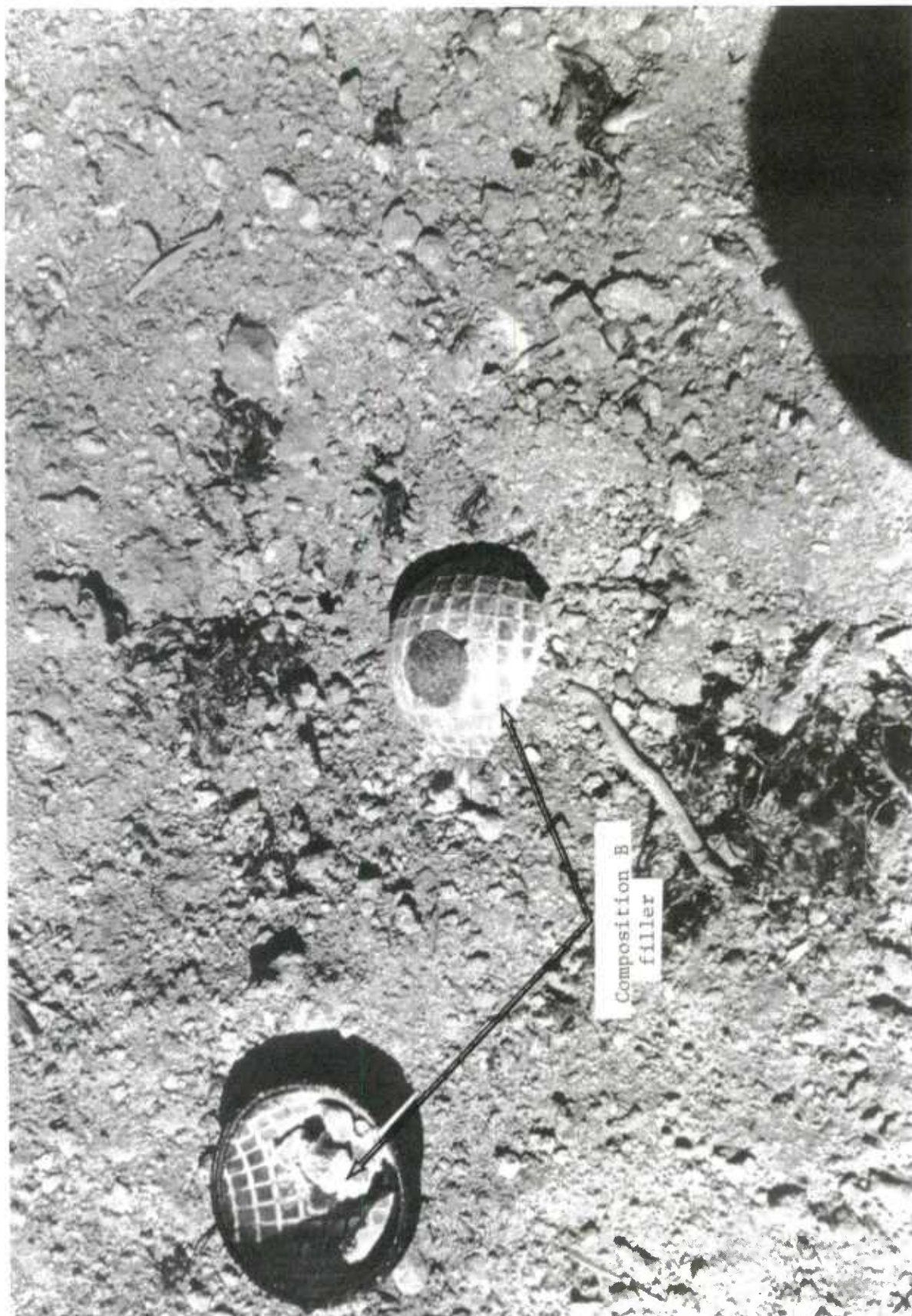


FIGURE 30. HEMISPHERE FROM SAFE SEPARATION OF BLU 63 BOMBLETS AT 25.4 MM SPACING SHOWING DISLODGED EXPLOSIVE FILLER



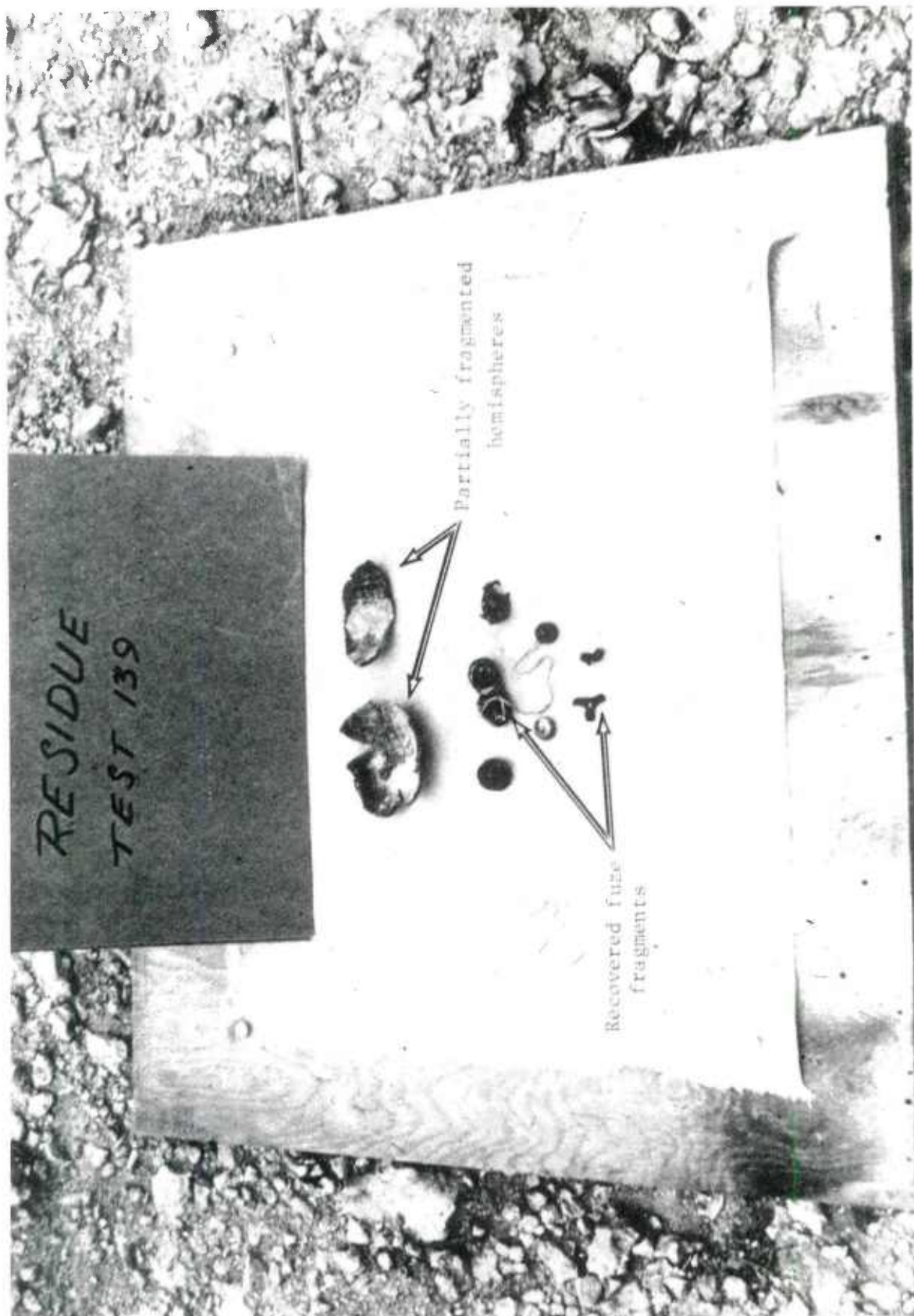
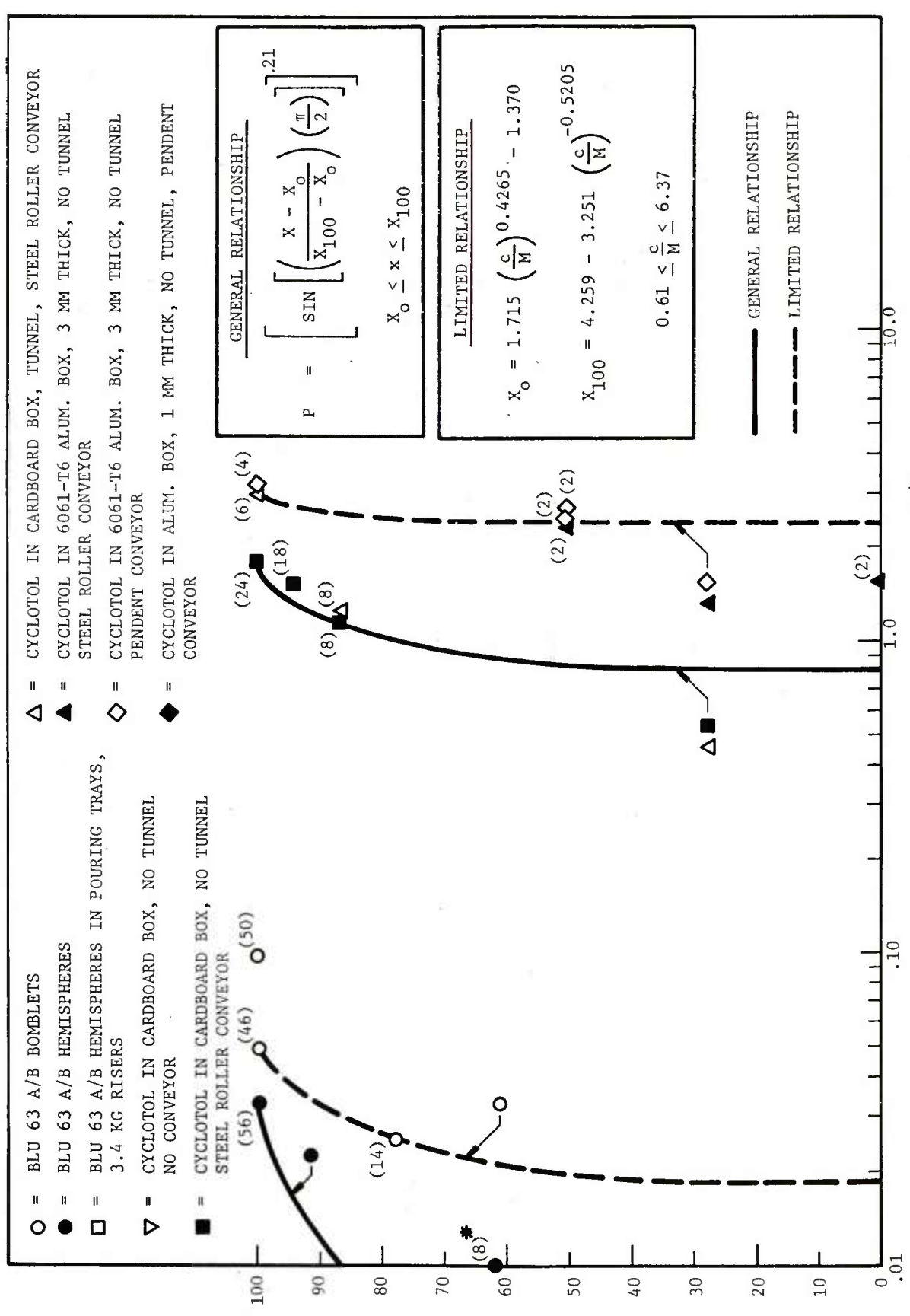


FIGURE 31. RESIDUE FROM SAFE SEPARATION TEST BLU 63 BOMBLETS  
(12.7 MM SEPARATION)





\*At 0.00

FIGURE 32. PROBABILITY OF NO DETONATION PROPAGATION VS SCALED DISTANCE

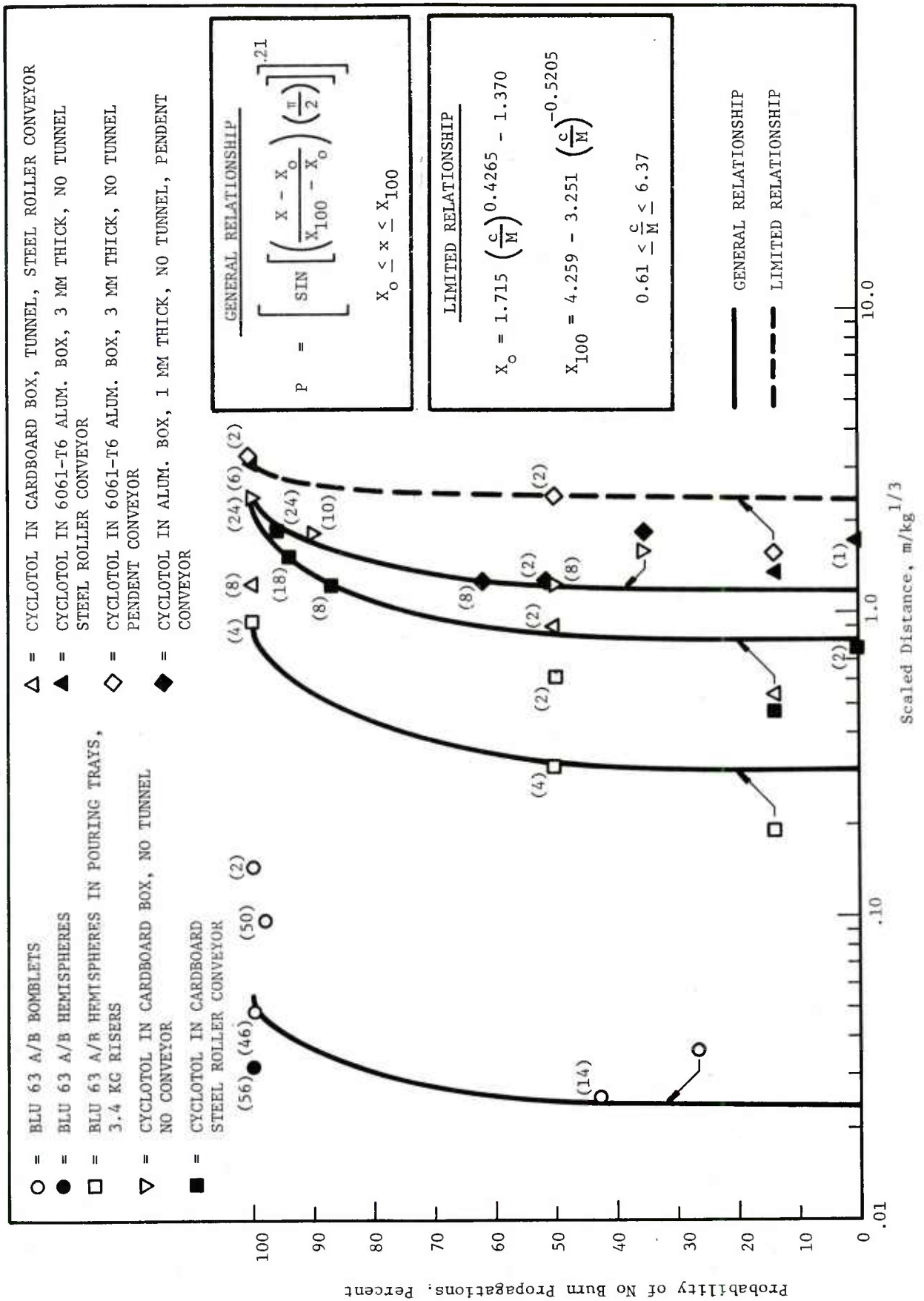


FIGURE 33. PROBABILITY OF NO BURN PROPAGATION VS SCALED DISTANCE

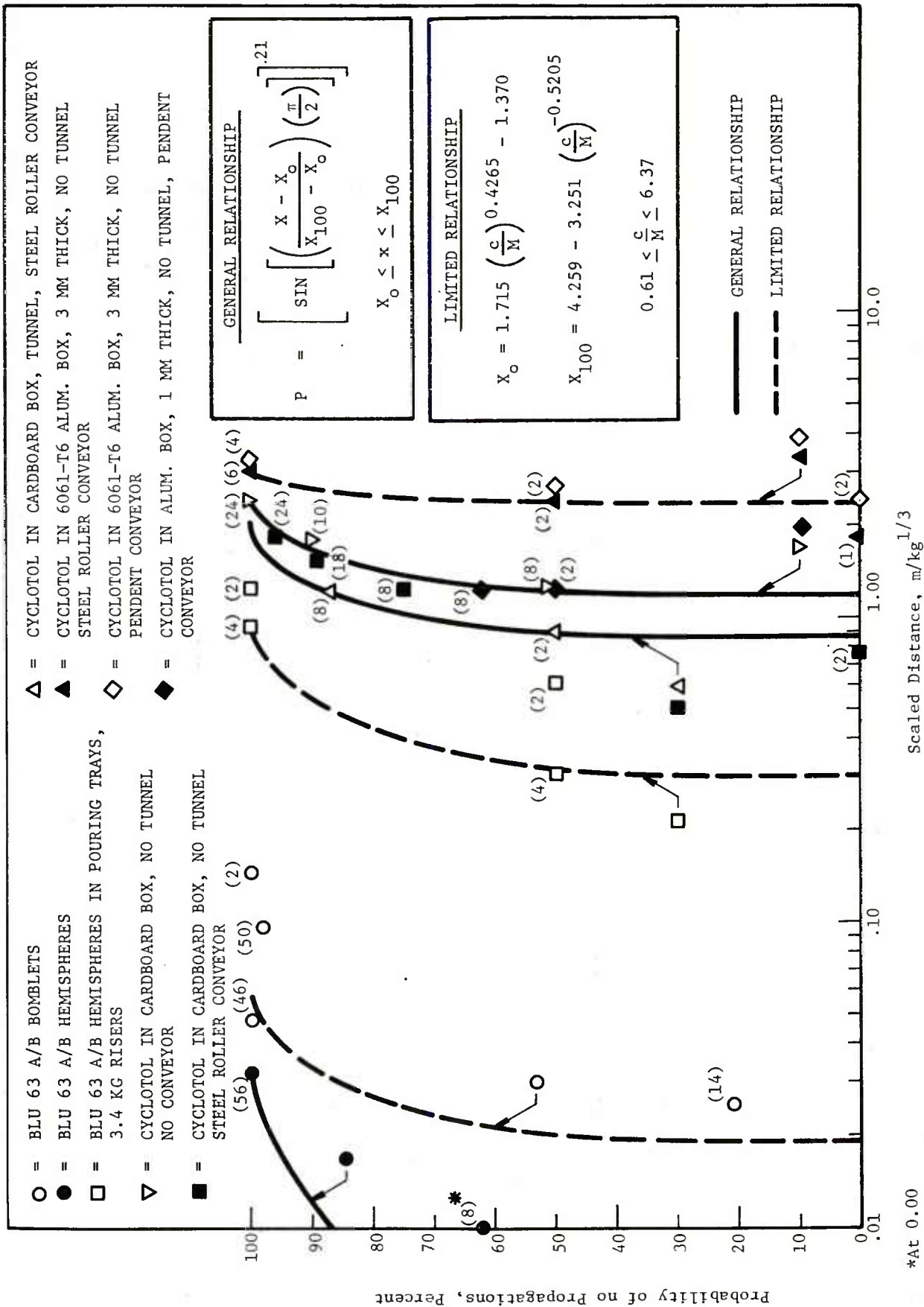


FIGURE 34. PROBABILITY OF NO PROPAGATION VS SCALED DISTANCE

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